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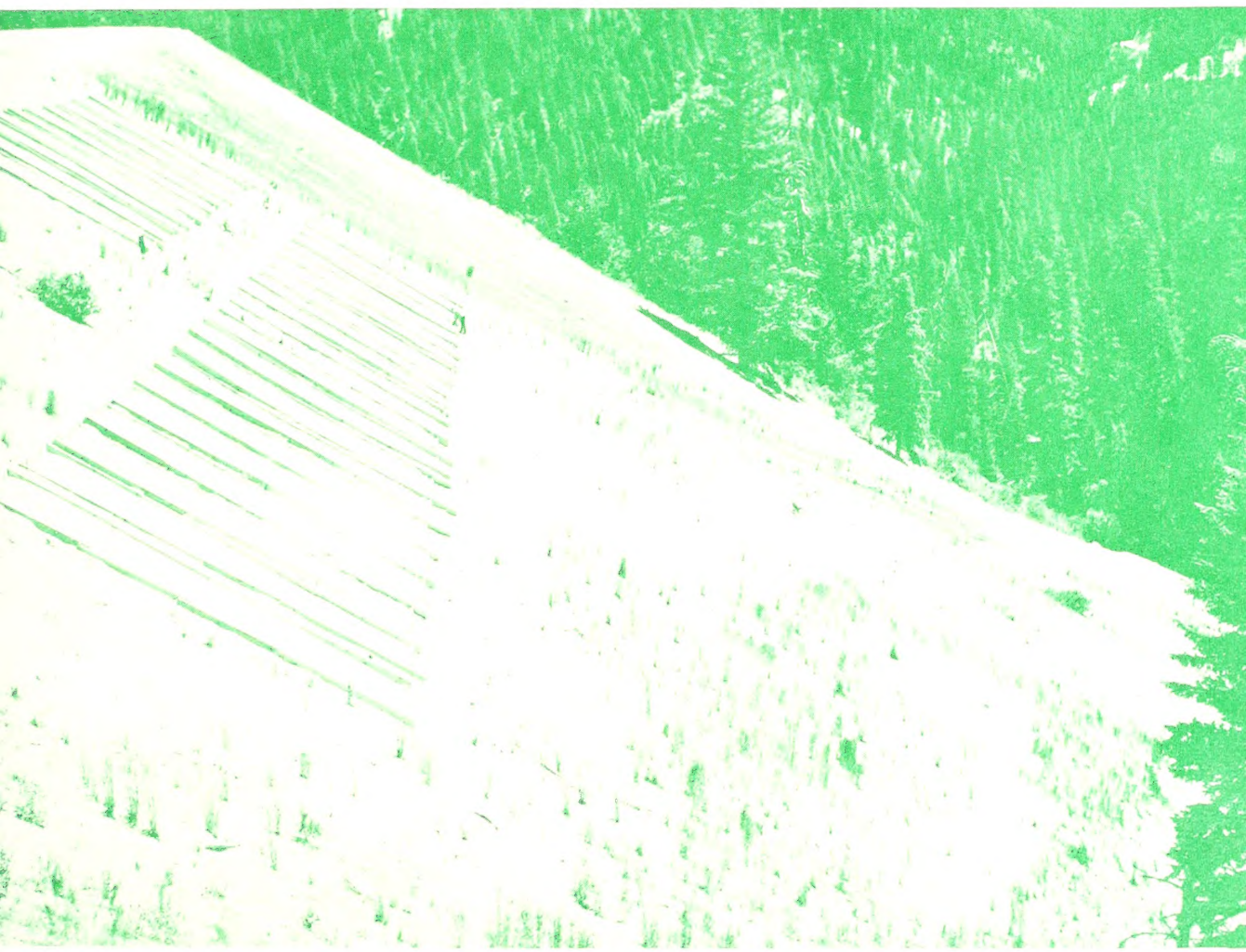
Walter F. Megahan



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Ogden, Utah 84401

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The Author

WALTER F. MEGAHAN is Principal Research Hydrologist and Leader of the Idaho Batholith Ecosystems Research Work Unit in Boise, Idaho. He holds bachelor's and master's degrees in Forestry from the State University of New York, College of Forestry, at Syracuse University, and a doctoral degree in Watershed Resources from Colorado State University. He served as Regional Hydrologist for Intermountain Region of the USDA Forest Service in Ogden, Utah, from 1960 to 1966 and has been in his present position since 1967.

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Deep-rooted plants for erosion control on granitic road fills in the Idaho Batholith

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Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401
Roger R. Bay, Director

Abstract

Numerous studies suggest that ponderosa pine (Pinus ponderosa Laws.) should reduce mass erosion hazards on road fill slopes. A study, designed with 3 replications of 10 treatments on 1/200-acre study plots, was conducted to evaluate how well ponderosa pine survives, grows, and reduces surface erosion on granitic road fills in the Idaho Batholith. The study was installed in 1968 and continued through 1972. Tree survival averaged about 97 percent after four growing seasons. Fertilizer increased planted tree growth an average of 95 percent during the year of peak effect. Tree planting, coupled with straw mulch and erosion netting, reduced erosion an average of about 95 percent over 3 years. Planted trees alone provided surprisingly large reductions in erosion, ranging from 32 to 51 percent. Planting ponderosa pine at a spacing of 3 by 3 to 4 by 4 feet is recommended as an erosion-control measure for granitic road fills in the Idaho Batholith.

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Figure 1.--Location map showing the Idaho Batholith and the study area.

INTRODUCTION

The Idaho Batholith is a 16,000-square-mile expanse of granitic rocks located in central Idaho (fig. 1). Much of the region is characterized by steep slopes and shallow, coarse-textured soils overlying granitic bedrock. Soils of this type have been shown to be extremely erodible (Anderson 1954; André and Anderson 1961).

The potential for erosion following road construction on side slopes in the Batholith is greatly increased within and sometimes beyond the road prism. Some factors causing the increase are: interruption of subsurface flow; removal of vegetative cover; destruction of natural soil structure; cut and fill slopes, which necessarily exceed the original slope gradient; and decreased infiltration rates on portions of the road. Megahan and Kidd (1972) reported on a 6-year study of erosion from secondary logging roads in the Zena Creek area of the Payette National Forest. Erosion on the area disturbed by road construction averaged 770 times greater than that occurring on nearby undisturbed watersheds.

In general, the erosion potential probably is increased more on the fill portions of a road than on the cut portions. Hydrologic analysis of the Zena Creek logging study area conducted by the Payette National Forest in 1966 showed that surface erosion on fills was an estimated 1.75 times that on road cuts. Evaluations also showed that material moved by mass erosion (landslides) amounted to almost as much as that resulting from surface erosion. Most landslides in the Zena Creek area occurred in the fill portions of roads.

Bethlahmy and Kidd (1966) reported that grass seeding, coupled with straw mulch, bound in place by erosion net, reduced surface erosion on a granitic road fill by about 98 percent the first year. However, the Payette National Forest hydrologic analysis on Zena Creek showed that an established grass cover did not prevent mass erosion of road fill surfaces. In some cases, as soon as the fill became sufficiently saturated with moisture, it "melted" and flowed down the hillside like wet concrete. The conclusion was that grass roots cannot bind a massive sandy fill together if the fill is standing at greater than its natural angle of repose.

Corbett and Rice (1966) found a similar situation in southern California. Mass movement was five times greater on brushlands converted to grass than on unconverted brushlands. Apparently, the deep-rooted brush provided more stability than that maintained by the grass after conversion. Bishop and Stevens (1964) and Swanston (1967) stated that mass erosion was reduced by tree roots on shallow soils in southeast Alaska. Gray (1969) summarized the literature and showed that trees tend to reduce mass erosion by mechanical reinforcement from roots, soil moisture depletion from transpiration, and providing a surcharge from the weight of the trees. Trees can have a destabilizing effect because of windthrowing and root wedging; however, he concluded that the net effect of tree cover is to increase mass stability.

In summary, a major problem associated with road construction on steep granitic lands is that of stabilizing road fills with regard to *both* surface and mass erosion. Research has shown that surface erosion on road fills can be greatly reduced and areas of mass erosion can be stabilized by deep-rooted vegetation. Thus, the problem is to find a way of establishing vegetation that will reduce both types of erosion. Shrub planting presents possibilities; however, at the outset of this study, tree planting was the most logical solution. Tree planting is used extensively throughout the Southeast to successfully control surface erosion (USDA Agricultural Research Service 1967). The question arises as to which species is best suited for this purpose on Idaho Batholith lands. Preferably, the species used should be a native that (1) has a wide habitat range in the Idaho Batholith; (2) is well adapted to the mineral soils found in harsh, steep sites; (3) has a rapidly growing and extensive root system with a taproot if possible; and (4) is readily available as planting stock or seed, or both.

Ponderosa pine (*Pinus ponderosa* Laws.) is a species that meets most of the above requirements. This native species is naturally distributed over most of the Idaho Batholith (Munns 1938). It is found as a climax species on warm, dry sites or, more commonly, as a seral species on cooler, moister sites.

Road fills on granitic soils constitute harsh sites for vegetative growth and survival of most species. Coarse-textured surfaces can be hot during the summer because of the lack of plant cover and can dry rapidly, at least on the surface, during rainless periods. Curtis and Lynch (1957) showed that ponderosa pine survival and growth are most dependent on available soil moisture. They found that seedlings possessed the ability to withstand prolonged drought and high surface temperatures. Drought resistance was primarily due to rapid growth of the root system, especially the taproot. Tree growth was more rapid when water use by competing vegetation was minimized and when sunlight was maximized.

Road fills necessarily exceed the depth of the original soil, often on the order of two to five times or more. Summarizing edaphic requirements of ponderosa pine, Curtis and Lynch (1957) stated, the species probably reaches its best development on well-drained, deep, sandy gravel and clay loams. Olson and others (n.d.) found the most important soil-growth relationship for ponderosa pine to be a direct increase in growth with soil depth for three different kinds of soils. Similar results were found by Cox and others (1960).

The rooting characteristics of ponderosa pine are probably a causal factor of drought resistance and growth response. Ponderosa pine develops a strong taproot, that is considered to be deep (Kramer 1949). Curtis and Lynch (1957) stated that root growth is rapid and continues after cessation of top growth. They reported average lengths of 22.4 inches for roots on 1-year-old natural seedlings and 60.7 inches for 4-year-old seedlings on severely burned sites with southerly aspects on coarse granitic soils in Idaho. Similar results were found by Boldt and Singh (1964), who reported root depths on planted 2:1 ponderosa pine stock of 2, 4.9, and 6.4 feet, and 1, 2, and 4 years, respectively, after planting in Nebraska.

Based on the above studies of rooting characteristics, ponderosa pine seems to be morphologically well suited to providing mechanical stability for mass erosion on road fills, certainly better suited than grass. Use of this species for erosion control on road fills in the Idaho Batholith has other advantages. Ponderosa pine is a valuable commercial species throughout its range. In addition, planting stock is readily available from local nurseries, as is seed to a somewhat lesser degree. Finally, the silvics and forest management practices for ponderosa pine are known and accepted for the most part by land managers.

The present study was designed to evaluate the effect of ponderosa pine with and without surface amendments on surface erosion. Seeded grass plots were also included to provide a comparison with earlier studies. No attempt was made to evaluate decreases in mass erosion hazard due to tree planting because such studies are extremely involved and beyond the scope of present efforts and because studies elsewhere provide strong evidence that ponderosa pine should increase the mass stability of granitic road fills. Other objectives of the present study were to provide information on tree survival and growth and some insight into the basic surface erosion processes occurring on granitic road fills. This report will be devoted to evaluating the effects of ponderosa pine on surface erosion and to presenting data on tree survival and growth. Results pertaining to basic erosion processes will be reported elsewhere.

METHODS

Description of the Study Area

Study-site selection was guided by the following criteria:

1.--Variation in slope and aspect would be minimal among treatments within one replication;

2.--Replications would be on such harsh-site conditions as the south or west aspects of steep slopes with little or no vegetative cover;

3.--Some variation in slope and aspect could be tolerated among replications, but major variations would be avoided;

4.--Fill slopes would be large enough to accommodate at least one replication of contiguous treatments at a single location.

A suitable study site was found on a large fill slope on the Deadwood River road, Emmett Ranger District, Boise National Forest. The area is at an elevation of 4,700 feet on a steep, southwest-facing slope about 300 feet above the Deadwood River (fig. 1). A *Pseudotsuga menziesii/Physocarpus malvaceus* habitat type existed on the slope prior to road construction. (Habitat nomenclature from work by Robert D. Pfister, Robert Steele, and others in unpublished reports available at the Forestry Sciences Laboratory, Boise, Idaho.)

Specifications for the study site actually exceeded the criteria outlined above because the fill slope surface was uniform and averaged about 200 feet in length. This uniformity made it possible to install all three replications at the same location, under apparently similar site conditions, thus minimizing site contributions to experimental error (fig. 2). The road fill had a southwest aspect and a slope gradient ranging from 70 to 75 percent. The fill was constructed in 1957, about 11 years prior to the installation of this study. The area studied had been unsuccessfully seeded with grass at least twice prior to study installation. Failures may have been due to (1) excessive deposition of material resulting from road maintenance operations and from reconstruction of nearby portions of the road following an 11-day storm in December 1964; (2) surface erosion on the road fill; and (3) big game use. All plot surfaces were essentially bare at the time of study installation.

Figure 2.--The study site on a road fill approximately 200 feet long on the Deadwood River Road. Arrow points to vehicle, which provides a perspective of the size of the road fill. (Photo taken May 1968.)

Study Design and Installation

Plots used in the study were in a randomized block design with three replications. Each replication consisted of nine different treatments plus a control:

1. Control

2. Seed (grass) straw mulch, erosion net, fertilizer

3. Seed (ponderosa pine), straw mulch, erosion net, fertilizer

4. Seed (ponderosa pine), straw mulch, erosion net

5. Plant (ponderosa pine), 1.5 by 1.5-foot spacing, straw mulch, erosion net, fertilizer.

6. Plant (ponderosa pine), 1.5 by 1.5-foot spacing, straw mulch, erosion net

7. Plant (ponderosa pine), 2.5 by 2.5-foot spacing, straw mulch, erosion net, fertilizer

8. Plant (ponderosa pine), 2.5 by 2.5-foot spacing, straw mulch, erosion net

9. Plant (ponderosa pine), 1.5 by 1.5-foot spacing

10. Plant (ponderosa pine), 2.5 by 2.5-foot spacing

The seeded grass plot was included to provide a comparison of results to those of earlier studies. Seeded trees were used because initial treatment costs for tree seeding were less than those for tree planting. Fertilizers have been shown to produce dramatic increases in growth of ponderosa pine on forest soils elsewhere (Tarrent and Silen 1963; Cochran 1973). Road fills, especially those constructed from granitic materials, should show even greater response to fertilization. It was felt that spacing should be tested for effects on both growth and erosion. The spacings tested are closer than those normally used for reforestation; however, this was deemed necessary to minimize surface erosion on unmulched plots.

Other researchers have shown the advantages of plant cover, litter, or both for surface erosion control on granitic soils (Packer 1951; Bethlahmy 1967). Bethlahmy and Kidd (1966) found that straw mulch and netting were necessary to effectively reduce surface erosion on road fills seeded to grass during the early establishment period for grass. Because of a needle life of 2 years for ponderosa pine, the initial small-top size for planted or seeded trees, and the nature of the litter produced by such small trees, little erosion control was expected from planted trees, especially during the early years after planting. Thus, straw mulches were used on some planted tree plots. Mulches were expected to provide some additional benefit to tree growth by reducing soil temperatures, helping to reduce soil moisture evaporation, and discouraging competition from other species.

Erosion plots were 1/200 acre in size with dimensions of 7.25 by 30.0 feet. The long axis of each plot was oriented up and down the slope. Plots were constructed from 1- by 12-inch boards on the top and sides. A plastic-lined trough, 6 inches deep by 8 inches wide was placed at the downhill side to catch sediment. Inverted V-shaped deflector boards were installed on the uphill side of each plot to prevent rocks from rolling across the plots. Retainer boards were installed in the access strip between plots to prevent downslope soil movement during plot servicing. Straw mulch 1 to 2 inches thick was held in place by galvanized chicken wire (erosion net) stapled to the ground. Fertilizer used for planted trees consisted of one Treefeed Pellet (28-5-0) per tree placed at root level 2 inches uphill from the tree. This application amounted to 108.9 pounds per acre of nitrogen and 19.4 pounds per acre of phosphorus for the trees spaced 1.5 by 1.5 feet apart and 40.0 pounds per acre of nitrogen and 7.1 pounds per acre of phosphorus for the trees spaced 2.5 by 2.5 feet apart.

Plots were constructed in April 1968, as soon as snowmelt permitted. Following construction, straw mulch and erosion net were applied on appropriate plots. Trees were planted and fertilized the first week of May, in accordance with the experimental design. Unfortunately, trees were planted about 1 month later than the optimum time for planting at the site because of the time required for plot preparation. The 2-0 planting stock, which was obtained from the Lucky Peak Nursery near Boise, Idaho, was derived from local seed sources. Appropriate plots were seeded to grass and trees in October 1968. Grass species mixed in equal proportions were seeded by a cyclone seeder at a rate of 50 pounds per acre. Species used in the study were Topar pubescent wheatgrass; Tualatin oatgrass, Manchar smooth bromegrass, crested wheatgrass, and intermediate wheatgrass. The straw mulch was removed before applying seed and replaced immediately after. This procedure helped assure consistency in erosion measurements over time during preceding time periods, but would not be followed in production operations. Tree seed, treated to reduce rodent losses, was applied at a rate of 2.5 pounds per acre, or 275 seeds per plot. Seeds were hand placed through the mulch on each plot to assure contact with the soil surface and to provide proper spacing.

Excessive use by both deer and elk occurred on the study area, especially on the straw-mulched plots, following plot installation in April 1968. This use resulted from failure to recognize the study area as a major migration route and concentration area for big game. Such use continued throughout much of the following summer in spite of concentrated prevention efforts with various kinds of repellents. Intensive animal use caused considerable trampling damage, especially on mulched plots. A gameproof fence was installed around the study plots in early September 1968 to prevent further damage. However, growth and mortality measurements in October showed that 40 percent of the planted trees had died primarily because of trampling by big game. At this time, all trees were carefully mapped to assure future identification. The following spring (April 1969) 2-0 trees were replanted by the same method as before (including fertilization) at all open locations in the plots. This procedure again provided a complete study, but the fence prevented the confounding effect of big game use.

Data Collection

Beginning in 1969, growth and mortality data were collected each year during late August, following the active growth period of ponderosa pine. Because two populations were sampled, it was necessary to record growth separately for all 1968- and 1969-planted trees. A tree was considered dead if it exhibited no green needles at the time of sampling. Height was measured from the top of the previous year's terminal bud scar to the top of the present year's leader bud. Seeded-tree survival was recorded by counting all green trees that were visible above the mulch. Seeded grass survival was obtained by counting the number of live plants occurring in a 1-square-foot circular plot placed at 10 equal intervals along the long axis through the center of each plot.

Beginning in 1969, plot troughs were cleaned about May 30 of each year to evaluate overwinter erosion rates. Troughs for all unmulched plots were cleaned approximately once a week throughout the summer and early fall. Weekly cleaning was necessitated by the higher erosion rates occurring on these plots. A recording rain gage was operated on the study site throughout the summer-fall servicing period. Prior to snowfall, on about October 15, all plots were cleaned again in preparation for winter.

All growth, survival, and erosion data were recorded on schedule until October 1972, which provided 4 years of data for growth and survival and 3-1/2 years of data for erosion.

RESULTS

Plant Survival

Planted-tree survival was excellent on all plots throughout the 4-year study period (table 1). To illustrate, 6 of the 18 study plots had 100 percent survival at the end of 4 years and only 2 plots had less than 95 percent survival.

An average of 12 percent of the tree seeds placed on the plots at the start of the study resulted in countable trees at the end of the first year; after 4 years, this figure had dropped to 5 percent (table 1). More trees were counted the third year than the second. Causal factors probably include sampling error and the possibility that natural seeding occurred from nearby trees. By the end of the study, there were far fewer trees per acre on seeded plots than on planted plots. This, coupled with reduced vigor of seeded trees on both fertilized and unfertilized plots, resulted in greatly reduced canopy cover on seeded tree plots as compared to planted tree plots (fig. 3, 4, and 5).

Plant density on the seeded grass plots decreased rapidly from over 17 plants per square foot the first year to less than 1 plant per square foot the fourth year. Such decreases are common on road fills seeded to grass in the vicinity. However, the lack of vigor evidenced by the limited crown development on the grass plants in figure 6 was not expected. Lack of vigor was probably the result of a severe grasshopper infestation that occurred in this area during both 1971 and 1972. Grasshoppers seriously damaged most shrubs, forbs, and grasses in the area, but had little effect on pine trees.

Table 1.--*Average plant survival by years on granitic road fills*

Year	Planted trees		Seeded trees		Seeded grass
	Percent	*Number/acre*	*Percent*	*Number/acre*	*Plants/ft²*
1969	98.5	13,199	12.2	6,700	17.2
1970	97.9	13,118	9.3	5,133	2.6
1971	97.8	13,105	10.0	5,500	1.2
1972	96.9	12,985	5.0	2,767	0.8

*Figure 3.--Planted ponderosa pine (*Pinus ponderosa*) at 1.5-foot spacing with mulch and fertilizer. (Photo taken May 1972.)*

*Figure 4.--Planted ponderosa pine (*Pinus ponderosa*) at 2.5-foot spacing with mulch and fertilizer. (Photo taken May 1972.)*

Figure 5.--Seeded ponderosa pine (Pinus ponderosa) with mulch and fertilizer. (Photo taken May 1972.)

Figure 6.--Seeded grass with mulch and fertilizer. (Photo taken May 1972.)

Height Growth of Planted Trees

Height-growth data were recorded separately for individual trees planted in 1968 and 1969, in the likely event that the two populations were not comparable (statistical analysis of the data verified that they were not). A standard analysis of variance was conducted for each year of each data set. Results are summarized in table 2.

There were highly significant differences in growth on the three replications in both data sets for all years. Differences were caused by replication 1 which consistently had higher growth than replications 2 and 3. Based on an overall average, replication 1 had 42 percent greater growth than replications 2 and 3. Replication 1 was the block of plots in the upper one-fourth of the road fill; the other two replications were lower on the fill slope (fig. 2). Apparently, tree growth tends to be greater in the upper portions of the fill slope, possibly in direct response to greater depth of fill materials and increased moisture collected on the road surface. Similar trends in growth of ponderosa pine with soil depths have been noted on natural soils by investigators cited earlier.

Average annual height-growth values for all years in each data set are plotted on figure 7. Curves to illustrate apparent time trends are shown to facilitate interpretation. Notice the low growth and especially the low treatment effect during the first year after planting the 1968 trees; similar results were not obtained for the 1969 trees. The difference might be explained by the fact that the 1968 trees were planted about 1 month late because of the time required to construct erosion plots; the 1969 trees were planted on schedule.

Figure 7 also shows that growth tends to decrease after 1970. This result differs from that observed by Hall and Curtis (1970), who reported that the rate of seedling height growth increased steadily the first 10 years for plantings in the Town Creek area of the Boise National Forest. However, Lynch (1958) showed that height growth of ponderosa pine decreased markedly as competition between trees increased. Thus, the decreasing growth trend found in this study apparently resulted from increased competition as closely spaced trees grew larger (fig. 3 and 4).

The overall treatment effects (table 2) were statistically significant for all years in both data sets, mostly at the 99 percent level. In order to better define treatment effects, individual treatments were compared against one another using Hartley's multiple range test procedure (Snedecor 1956, p. 253). The effects of fertilizer are immediately apparent on figure 7. Growth on fertilized plots was significantly greater (95 percent level) than growth on all unfertilized plots in all data

Table 2.--*Level of significance obtained from analysis of variance tests for the effects of treatments and replications on height growth*

Year	1968 Trees		1969 Trees	
	Replication	Treatment	Replication	Treatment
	Percent			
1969	99	95	--	--
1970	99	99	99	99
1971	99	99	99	99
1972	99	95	99	99

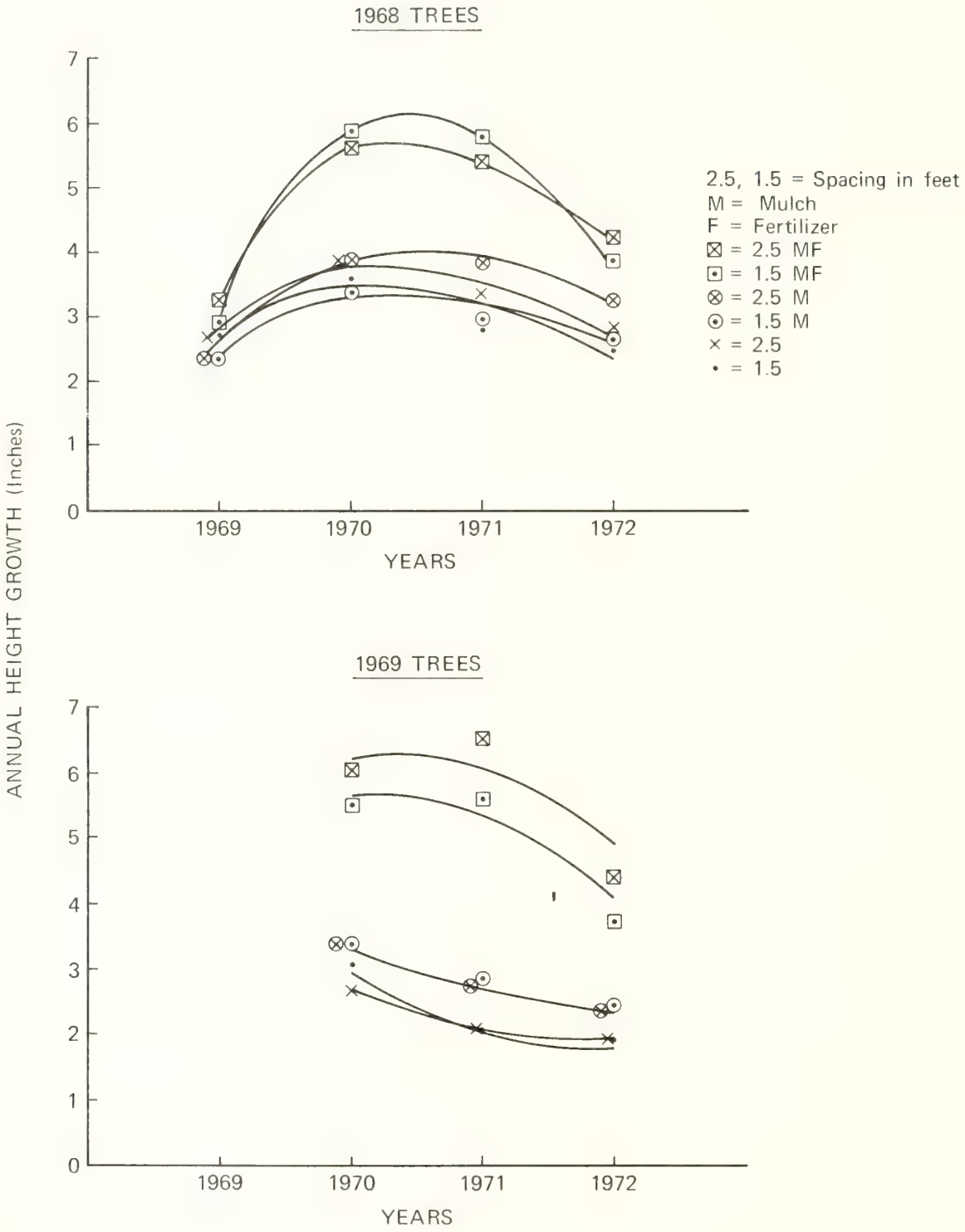

Figure 7.--Average annual height growth of ponderosa pine (Pinus ponderosa) *with various combinations of spacing and treatment for all study years.*

Table 3.--*Average percent increase in height growth following fertilization of ponderosa pine on granitic road fills*

Year	1968 trees	1969 trees
	Percent	
1969	32	--
1970	60	71
1971	70	116
1972	38	68

sets, except those for 1969 and 1972 on the 1968 trees. Even in these years, however, fertilization did increase growth over some unfertilized plots. Mulching appears to have increased growth somewhat, especially for the 1969 trees; however, increases were significant only at the 90 percent level, and then in but a few cases. Wider spacing also tended to increase growth in some instances, but again increases were detected only at the 90 percent level.

Table 3 was developed to present a clearer picture of average fertilizer effects. Growth is expressed as the average percent increase in growth on plots treated with mulch and fertilizer compared to plots treated with mulch alone. There is a tendency for fertilizer effects to decrease 3 to 4 years after application. Although fertilizer was effective in increasing growth on both sets of trees, the effect was greatest on the 1969 trees. The additional growth increase was probably caused by the fact that a second fertilizer pellet was used when trees were replanted in 1969. This type of fertilizer releases nutrients slowly; some original tree pellets placed in 1968 were still recognizable at the time of planting in 1969. Thus, the 1969 trees received more fertilizer than the 1968 trees.

Erosion Control

Erosion data were summarized by water years (Oct. 1-Sept. 30) beginning in October 1969; consequently, data were provided for 3 complete years, 1970, 1971, and 1972. Additional data were available for the summer of 1969, but were not analyzed because of undue soil disturbance resulting from plot maintenance during the period.

Previous studies (Megahan and Kidd 1972) indicated that the standard deviations of data from erosion plots similar to those used in the present study tend to be proportional to the mean. Consequently, a log (X + 1.0) transformation of erosion data was used to provide a more reliable statistical test of treatment effects.

Statistical analyses were made for each year of data and included a standard analysis of variance to detect overall treatment and block effects and a sequential multiple range test to compare individual treatment effects.

Analysis of variance showed highly significant treatment effects (99 percent level), but no block effects for all years of data tested. Results of the multiple range tests are summarized in figure 8. Variations in erosion by years primarily reflect annual variation in erosion energy available from raindrop impact and wind. No significant differences in erosion were observed among the various mulched plots nor the 1.5- by 1.5- and 2.5- by 2.5-foot unmulched plots. Compared to control plots, planted trees without mulch reduced average annual erosion rates by 48, 32, and 51 percent in 1970, 1971,

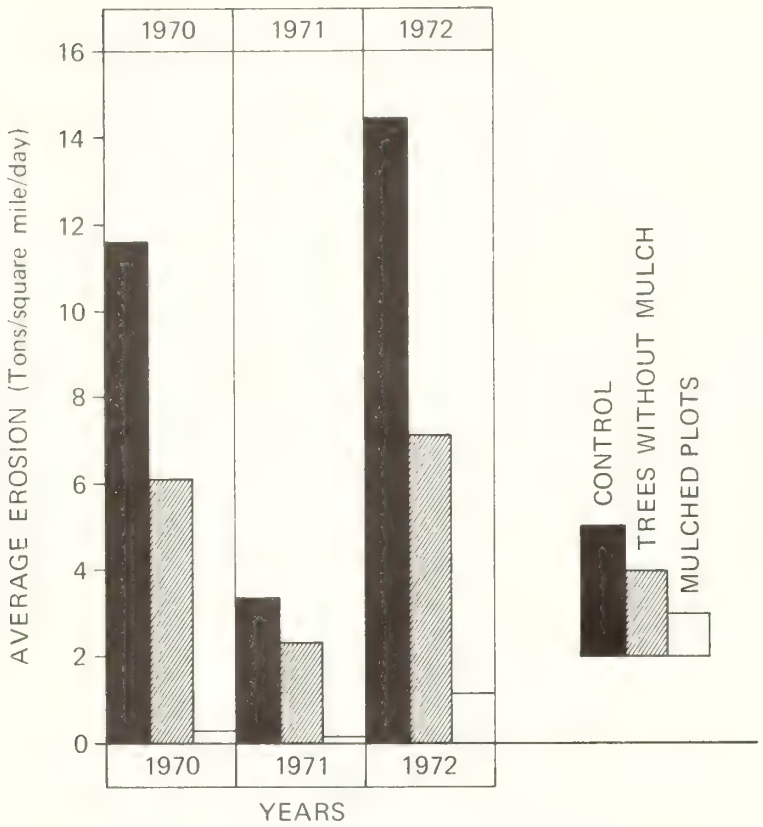

Figure 8.--Average annual surface erosion by treatment on granitic road fills.

and 1972, respectively; reductions were significant at the 95 percent level in 1970 and 1972 and at the 90 percent level in 1971. Mulches caused a highly significant reduction in erosion that averaged about 95 percent of that occurring on the control plots for the 3 years of data.

Mulch effects would be expected to lessen over time as the mulch material deteriorates. Slight time trends did appear on most plots; overall average reductions in erosion of 98, 94, and 92 percent were recorded for the 1970, 1971, and 1972 water years, respectively. Similarly, the growth of trees on the unmulched plots would be expected to provide greater erosion protection over time; however, no consistent time trends were detected nor were block effects with respect to erosion, even though growth averaged about 40 percent higher in the block located near the top of the road fill.

DISCUSSION AND CONCLUSIONS

Mass failure of road fills is an important component of the overall erosion process on slopes in the Idaho Batholith. A large body of studies elsewhere indicate that deep-rooted vegetation, including trees and shrubs, should increase the mass stability of fill slopes. Ponderosa pine possesses a number of attributes that makes it particularly attractive for this purpose. In this study, the intrinsic value of ponderosa pine for increasing the mass stability of fill slopes was accepted as fact and two logical followup questions were investigated: (1) how well does ponderosa pine survive and grow on roadfills and (2) how well does ponderosa pine control surface erosion on road fills?

Performance of planted and seeded ponderosa pine and a seeded grass mixture was evaluated. Survival of the planted pine was high, averaging about 97 percent after four growing seasons. Growth and vigor of the planted trees far exceeded that of the seeded trees and grass. Poor grass responses were atypical, probably the result of a severe grasshopper infestation during 1971 and 1972. Fertilizer increased the annual growth of planted pine by an average of about 95 percent during the year of peak effect. There was some indication that fertilization effects tended to decrease after 3 or 4 years; however, growth still averaged about 45 percent greater than that of trees on unfertilized plots.

Wider spacing of planted trees also tended to increase growth, but not consistently. There was an overall decrease in growth over time that was probably caused by intertree competition. Increasing tree spacing from 1.5 by 1.5 to 2.5 by 2.5 feet did not increase erosion. Considering growth responses, planting costs, and comparable erosion, the 2.5- by 2.5-foot spacing is preferable. Actually, 3- by 3-foot or even 4- by 4-foot spacing should reduce the possibility of growth stagnation and probably would still provide effective erosion control.

Straw mulch held in place by netting was by far the most effective means of reducing surface erosion. Effects were similar on both the tree and grass plots. Mulch effects tended to diminish slightly over time, but even after 3 years, mulch reduced erosion an average of 92 percent. Mulches provided additional benefit by increasing tree growth on many plots. Planted trees alone provided surprisingly large decreases in annual erosion rates, ranging from 32 to 51 percent.

In conclusion, planting ponderosa pine at 3- by 3- to 4- by 4-foot spacings is recommended as an erosion control measure on granitic road fills. If at all possible, trees should be fertilized to accelerate growth, especially root growth. Trees alone should reduce surface erosion by approximately one-third; additions of straw mulch, held in place by erosion net, will reduce surface erosion by about 95 percent.

Logistical problems should be minimal in road fill tree planting on an operational scale. Certainly, access is optimal. Moreover, many roads are constructed in connection with timber sales that require tree planting anyway. Good planting procedures, similar to those prescribed for timber sales, should be used. Planting stock of proper age should be as large as practicable, especially for new road fills.

Ponderosa pine appears as a climax or seral species in a variety of habitat types on natural slopes (table 4). Fill slopes may not be the same habitat type as the original slope because of the severity of the change in overall site conditions. However, the habitat type concept does provide a logical stratification of the site potential for the area. Thus, it is suggested that table 4 be used as a guide for planting ponderosa pine on road fills based upon the forest habitat type found on adjacent undisturbed slopes. Ponderosa pine is not suited for roadbed planting in the various alpine fir (*Abies lasiocarpa* (Hook.) Nutt.) habitat types; lodgepole pine (*Pinus contorta* Dougl.) is recommended for these areas.

Table 4.--*Role of ponderosa pine (*Pinus ponderosa*) in habitat types in central Idaho. (Work by Robert D. Pfister, Robert Steele, and others. Unpublished reports on file at Forestry Sciences Laboratory, Boise, Idaho.)*

Habitat types and phases	Major climax	Minor climax	Major seral	Minor seral
Pinus ponderosa series				
Pinus ponderosa/Agropyron spicatum	X			
Pinus ponderosa/Festuca idahoensis	X			
Pinus ponderosa/Purshia tridentata	X			
Pinus ponderosa/Symphoricarpos albus	X			
Pinus ponderosa/Symphoricarpos oreophilus	X			
Pseudotsuga menziesii series				
Pseudotsuga menziesii/Agropyron spicatum		X*		
Pseudotsuga menziesii/Festuca idahoensis		X*		
Pseudotsuga menziesii/Carex geyeri			X*	
Pseudotsuga menziesii/Calamagrostis rubescens			X*	
Pseudotsuga menziesii/Spiraea betulifolia			X	
a. Carex geyeri phase			X*	
b. Calamagrostis rubescens phase			X*	
Pseudotsuga menziesii/Symphoricarpos oreophilus				
a. Prunus virginiana phase		X*		
Pseudotsuga menziesii/Symphoricarpos albus			X	
Pseudotsuga menziesii/Physocarpus malvaceus			X*	
Pseudotsuga menziesii/Acer glabrum			X*	
Abies grandis series				
Abies grandis/Clintonia uniflora				X
Abies grandis/Vaccinium globulare				X
Abies grandis/Spiraea betulifolia			X	

*These habitat types extend beyond the natural range of ponderosa pine; therefore, ponderosa pine should not be used unless it occurs on undisturbed slopes in the area. Instead, selected shrub species should be investigated.

One final point is of interest. Earlier, it was pointed out that ponderosa pine is an important commercial species. Needless to say, the growing of sawtimber on road fills is not being advocated: however, road fill planting does permit some provocative possibilities for Christmas trees. Certainly, access is good for both the forest manager and the consumer. A number of forest managers have indicated an interest in this aspect of tree planting on road fills. The possibilities are worthy of further consideration, as long as the primary objective, tree planting for erosion control, is maintained.

This study showed that planting of deep-rooted vegetation (ponderosa pine) reduces surface erosion. Such plantings offer additional benefit over more conventional grass seeding because they lessen mass erosion hazards. However, deep-rooted vegetation should not be construed as a panacea for mass erosion on road fills because it will not prevent all landslides, nor substitute for careful road location, design, and construction practices. Tree planting does provide an additional safeguard that should be seriously considered.

REFERENCES

Anderson, H. W.
1954. Suspended sediment discharge as related to streamflow, topography, soil and use. Am. Geophys. Union Trans. 35:268-281.

André, J. E., and H. W. Anderson
1961. Variation of soil erodibility with geology, geographic zone, elevation and vegetation type in northern California wildlands. J. Geophys. Res. 66: 3351-3358.

Bethlahmy, Nedavia
1967. Effect of exposure and logging on runoff and erosion. USDA For. Serv. Res. Note INT-61, 7 p.

Bethlahmy, Nedavia and W. Joe Kidd, Jr.
1966. Controlling soil movement from steep road fills. USDA For. Serv. Res. Note INT-45, 4 p.

Bishop, Daniel M., and Mervin E. Stevens
1964. Landslides on logged areas in southeast Alaska. USDA For. Serv. Res. Pap. NOR-1, 18 p.

Boldt, Charles E., and Teja Singh
1964. Root development of ponderosa pine transplants at Lincoln, Nebraska. USDA For. Serv. Res. Note RM-20, 4 p.

Cochran, P. H.
1973. Response of individual ponderosa pine trees to fertilization. USDA For. Serv. Res. Note PNW-206, 15 p.
Corbett, Edward S., and Raymond M. Rice
1966. Soil slippage increased by brush conversion. USDA For. Serv. Res. Note PSW-128, 8 p.
Cox, G. S., R. C. McConnell, and L. M. Matthews
1960. Ponderosa pine productivity in relation to soil and landform in western Montana. Soil Sci. Soc. Am. Proc. 24:139-142.
Curtis, James D., and Donald W. Lynch
1957. Silvics of ponderosa pine. USDA For. Serv. Intermt. For. & Range Exp. Stn. Misc. Publ. 12, 37 p.
Gray, D. H.
1969. Effects of forest clear-cutting on the stability of natural slopes. Prog. Rep. Univ. Mich., Dep. Civ. Eng., 67 p.
Hall, D. O., and J. D. Curtis.
1970. Planting method affects height growth of ponderosa pine in central Idaho. USDA For. Serv. Res. Note INT-125, 8 p.
Kramer, Paul J.
1949. Plant and soil water relationships. 347 p. McGraw-Hill Book Co., Inc., New York.
Lynch, Donald W.
1958. Effects of stocking on site measurement and yield on second-growth ponderosa pine in the Inland Empire. USDA For. Serv. Res. Pap. INT-56, 36 p.
Megahan, W. F., and W. J. Kidd
1972. Effects of logging and logging roads on erosion and sediment deposition from steep terrain. J. For. 70:136-141.
Munns, E. N.
1938. The distribution of important forest trees of the United States. USDA Misc. Publ. 287, 176 p.
Olson, O. C., J. F. Arnold, and M. A. Coonrod
(n.d.) Some tree vigor-soil relationships on the Town Creek Plantation, Boise National Forest. USDA For. Serv., Boise Nat. For., 8 p.
Packer, Paul E.
1951. An approach to watershed protection criteria. J. For. 49:639-644.
Snedecor, George W.
1956. Statistical methods. Ed. 5, 534 p. Iowa State College Press, Ames, Iowa.
Swanston, Douglas N.
1967. Debris avalanching in thin soils derived from bedrock. USDA For. Serv. Res. Note PNW-64, 7 p.
Tarrant, Robert F., and Roy R. Silen
1963. Growth and nutrient uptake of young ponderosa pine after heavy fertilizer treatments. Am. Soc. Agron., Agron. Abstr., p. 72.
USDA Agricultural Research Service
1967. Notes on sedimentation activities calendar year 1966. 150 p.

WALTER F. MEGAHAN

1974. Deep-rooted plants for erosion control on granitic road fills in the Idaho Batholith. USDA For. Serv. Res. Pap. INT-161, 18 p., illus. (Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.)

The study was installed in 1968 and continued through 1972. Tree survival averaged about 97 percent after four growing seasons. Fertilizer increased planted tree growth an average of 95 percent during the year of peak effect. Tree planting, coupled with straw mulch and erosion netting, reduced erosion an average of about 95 percent over 3 years. Planted trees alone provided surprisingly large reductions in erosion, ranging from 32 to 51 percent. Planting ponderosa pine at a spacing of 3 by 3 to 4 by 4 feet is recommended as an erosion-control measure for granitic road fills in the Idaho Batholith.

OXFORD: 116; 116.65. KEYWORDS: erosion control, seeding, Idaho Batholith, granitic soil, fertilizer, mulching, tree growth, tree survival.

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REVEGETATION RESEARCH ON THE DECKER COAL MINE IN SOUTHEASTERN MONTANA

Eugene E. Farmer, Ray W. Brown, Bland Z. Richardson, and Paul E. Packer

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The research reported here is a contribution to the SEAM program. SEAM, an acronym for Surface Environment and Mining, is a Forest Service program to research, develop, and apply technology that will help maintain a quality environment and other surface values while helping meet the Nation's mineral requirements. SEAM is a partnership with all land managers, regional planners, mining industries, and political jurisdictions at all levels.

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REVEGETATION RESEARCH ON THE DECKER COAL MINE IN SOUTHEASTERN MONTANA

**Eugene E. Farmer, Ray W. Brown,
Bland Z. Richardson, and Paul E. Packer**

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401
Roger R. Bay, Director

EUGENE E. FARMER, Forest Hydrologist on the Watershed Protection and Rehabilitation research unit at Logan, Utah, joined the staff of the Intermountain Station in 1964. His principal interests have been in soil erosion and precipitation characteristics in mountainous terrain.

RAY W. BROWN is a plant physiologist with the Intermountain Forest and Range Experiment Station, stationed in Logan, Utah, since 1965. He received his B.S. and M.S. degrees in 1963 and 1965, respectively, from the University of Montana, and a Ph.D. in Plant Physiology in 1974 from Utah State University. His primary research interest and activity are in water relations and heat transfer characteristics of plants.

BLAND Z. RICHARDSON is a Research Forester stationed at the Forestry Sciences Laboratory of Intermountain Station, Logan, Utah. After completing engineering training at Yale University in 1944, Richardson was commissioned in the United States Air Force where he served until his retirement from active duty in 1952. Richardson received his B.S. degree in forestry from the University of Montana in 1963. In 1964 he joined Intermountain Station and was assigned to work in the field of watershed management. Since then he has been involved in a variety of research activities in that field.

PAUL E. PACKER is a 1939 graduate in forestry from the University of California. Subsequently he obtained an M.S. degree there. He has been employed as a research forester by the Forest Service for more than 30 years. He has made many research contributions in watershed management and is the author of more than 30 research publications. Among his most important accomplishments are development of watershed protection requirements for important western ranges and establishment of criteria for locating and designing logging roads to prevent sedimentation of streams. Since 1962 he has been project leader of the Watershed Protection and Rehabilitation research unit at Logan, Utah.

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Use of commercial names in this report is for information only, and does not imply endorsement by the U.S. Department of Agriculture.

ABSTRACT

First-year results of revegetation research at the Decker coal mine in southeastern Montana are described. Three types of main plots were located on overburden material: (1) a control plot, (2) an irrigated plot, and (3) a plot dressed with topsoil materials. Each main plot consists of 48 subplots for a total of 144 subplots. Treatments included different grass mixtures, fertilizer, and mulch on irrigated and unirrigated plots. On the basis of dry-weight grass production, several treatments produced acceptable first-year grass stands. The top-dressing of mine overburden appears to be a highly desirable revegetation practice. Generally, wheatgrasses (Agropyron spp.) have dominated the dry-weight production.

INTRODUCTION

The revegetation of coal mined lands in the Northern Great Plains has recently become a focal point of interest by various Federal and State agencies, and private groups. At least in part, this interest stems from the fact that little quantitative information is available concerning the revegetation of mine spoils in the Western United States. This knowledge gap has resulted in opinions on revegetation possibilities ranging from the most pessimistic forecasts to the most optimistic.

One surface mine of great recent interest is the Decker coal mine in southeastern Montana. The Decker mine, situated on lands owned by the State of Montana, was opened as a result of the recent increased national need for fuel resources. Over the next several years, this mine is expected to develop into one of the largest coal mines in the United States.

The Decker mine is located near Decker, Montana, just north of Sheridan, Wyoming. Commercial operations started in 1971 in a subbituminous coal seam averaging about 50 feet thick. The coal is buried under approximately 60 feet of overburden. This overburden material is removed from the coal bed with heavy equipment and placed into an adjacent cut from which the coal has been removed.

The soils in the area of the mine are clayey and loamy Ustic Aridisols, often containing a large amount of sodium on the clay particles. Parent materials, shales or sandstones, are usually at depths greater than 30 inches. The general physiography is a succession of smooth divides and broad drainage bottoms of rolling land. However, buttes of red scoria and shale outcrops are common landscape features; these sites are usually occupied by badlands vegetation (Brown 1971).

The natural vegetation of the general area reflects the annual precipitation of about 15 inches. It consists primarily of mixed grass prairie and scattered shrubs. The dominant vegetation on the gently rolling slopes is needle-and-thread (*Stipa comata*), green needle-grass (*S. viridula*), western wheatgrass (*Agropyron smithii*), blue grama, (*Bouteloua gracilis*), and big sagebrush (*Artemisia tridentata*). In the swales, salt grass (*Distichlis stricta*), western wheatgrass, and big sagebrush are dominants.

The research reported here includes the first-year results of a revegetation study at the Decker mine. The research was initiated during the summer of 1972, and plantings were made on mine overburden materials in October 1972. The major long-term objective of this study is to provide several alternative prescriptions for achieving a permanent plant cover on disturbed sites of the Decker coal mine.

SITE AND PLOTS

The site selected for study (fig. 1) was on level overburden material, chosen to avoid the effects of slope, aspect, and steepness, and to avoid complications associated with seed and plant nutrient movement through erosional processes. The overburden materials on the study site came from the original coal test pit, located about 200 feet east of the study site. These materials were graded level. Topsoil, as needed, was hauled to the site for the research study.

Three types of main plots were located on the overburden material: (1) a control plot, (2) an irrigated plot, and (3) a plot on which the overburden material was top-dressed with about 8 inches of soil materials that originated in the surface 3 feet. Each main plot consists of 48 subplots, each 8 feet square.

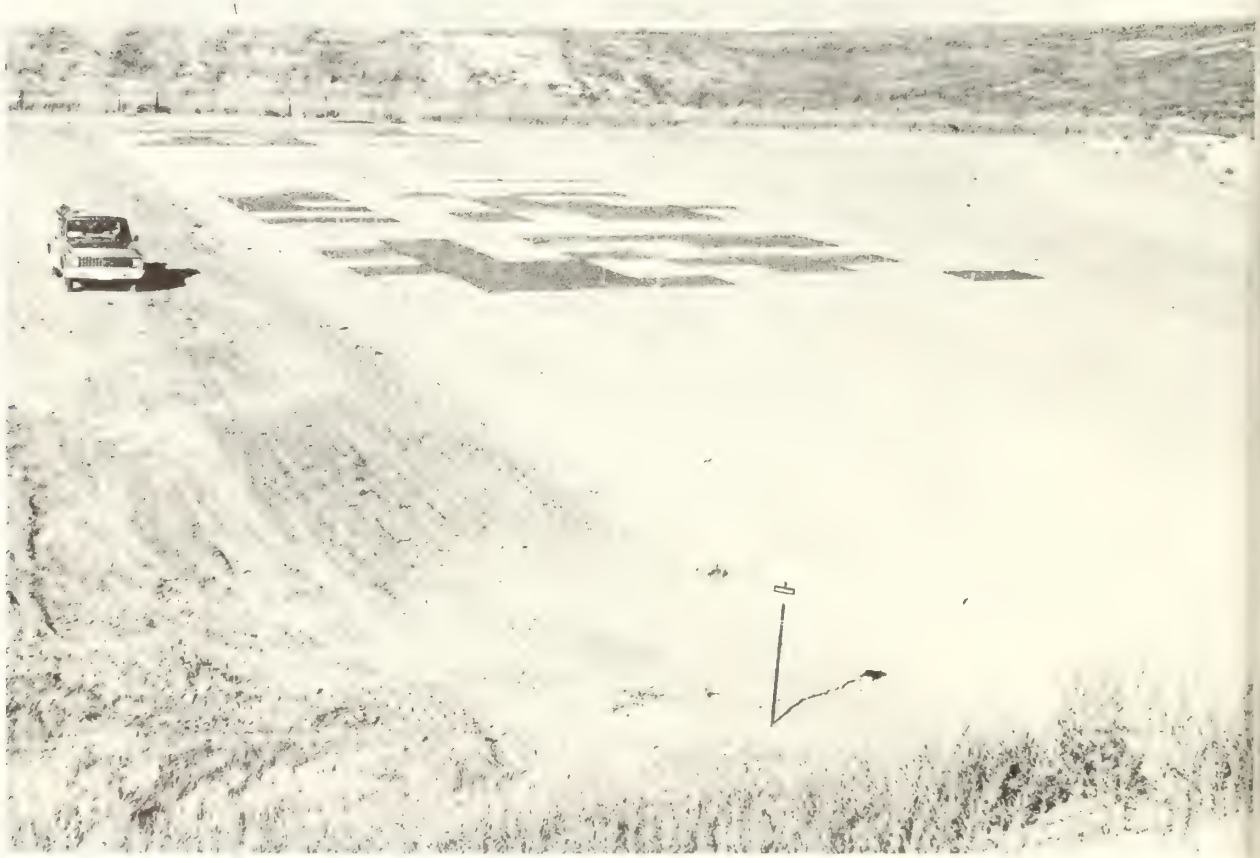

Figure 1.--View of the study site just after planting, October 1972; looking generally northeast. The darker areas are mulched subplots.

Results of analyses of 10 samples of Decker mine overburden materials are shown in table 1 (Hodder and Sindelar 1972). The study site generally tends toward the heavier soil textures, (samples 4 through 10). The top-dressed main plot has a slightly better soil structure than the main plots located on overburden materials, but soil chemistry does not appear to be appreciably different. Soil samples numbers 9 and 10 were taken from top-dressed main plot.

Table 1.--*Soil analyses of some overburden materials at the Decker coal mine*

Sample	pH	Total salts (Mmho/cm)	Available nutrients (p/m)		Texture
			P	K	
1	8.5	2.9	2.4	111	Sandy loam
2	7.2	.6	15.0	278	Sandy loam
3	7.0	.6	2.2	180	Sandy loam
4	8.8	1.6	0	153	Sandy loam
5	8.4	4.2	0	153	Clay
6	8.8	0.7	0.4	101	Loamy clay
7	8.4	2.2	0	234	Clay
8	8.8	.9	0	143	Clay
9	7.9	2.2	12.0	226	Sandy clay
10	8.2	3.0	15.0	199	Sandy clay

TREATMENTS

Twelve treatments were replicated four times on each main plot. The treatments were: three grass seed mixtures alone, and the mixture with fertilizer, or mulch, or both, table 2.

Table 2.--*Subplot treatments replicated four times on each of three main plots*

Grass mixture	Fertilizer	Mulch
Native	Yes	Yes
Pasture	Yes	Yes
Native + Pasture	Yes	Yes
Native	Yes	No
Pasture	Yes	No
Native + Pasture	Yes	No
Native	No	Yes
Pasture	No	Yes
Native + Pasture	No	Yes
Native	No	No
Pasture	No	No
Native + Pasture	No	No

Seed mixtures.--The grass seed mixtures consisted of: (1) native species, 2) introduced species, and (3) a mixture of native and introduced species. All seed ixtures were combined with rice hulls as a carrying agent. Species present in each ixture were:

	Lb/acre
NATIVE SPECIES	
Green needlegrass *(Stipa viridula)*	4.5
Western wheatgrass *(Agropyron smithii)*	6.0
Blue grama *(Bouteloua gracilis)*	3.0
Little bluestem *(Andropogon scoparius)*	1.5
Sideoats grama *(Bouteloua curtipendula)*	3.0
Indian ricegrass *(Orysopsis hymenoides)*	1.5
Slender wheatgrass *(Agropyron trachycaulum)*	4.5
Big bluestem *(Andropogon gerardi)*	1.5
Total	25.5
INTRODUCED SPECIES	
Fairway crested wheatgrass *(Agropyron cristatum)*	5.0
Nordan crested wheatgrass *(Agropyron cristatum)*	3.0
Russian wildrye *(Elymus junceus)*	4.5
Pubescent wheatgrass *(Agropyron trichophorum)*	3.0
Intermediate wheatgrass *(Agropyron intermedium)*	5.0
Smooth brome (Manchar) *(Bromus inermis)*	3.0
Winter rye *(Secale cereale)*	3.0
Tall wheatgrass *(Agropyron elongatum)*	3.0
Total	25.5
NATIVE PLUS INTRODUCED SPECIES	
Fairway + Nordan crested wheatgrass *(Agropyron cristatum)*	4.5
Green needlegrass *(Stipa viridula)*	3.0
Smooth brome *(Bromus inermis)*	3.0
Western wheatgrass *(Agropyron smithii)*	4.5
Russian wildrye *(Elymus junceus)*	3.0
Blue grama *(Bouteloua gracilis)*	1.5
Intermediate wheatgrass *(Agropyron intermedium)*	3.0
Slender wheatgrass *(Agropyron trachycaulum)*	3.0
Total	25.5

All native grass seed used in this study originated in the general area of Decker, Montana. The native seed was collected by hand during the summer and cleaned before use. The native species selected are some of the principal dominants in the area, but also included some subdominants and seral species. The introduced species, all of which grow successfully in the vicinity of the Decker mine, were obtained commercially. All species selected appeared to have potential for revegetation use as evidenced by their observed occurrence and growth on other disturbed sites (road cuts and fills) in the area.

Fertilizer and mulch.--Fertilizer was a commercial granular 15-40-5 type mixed with silica sand carrying agent. Commercial sphagnum peat moss, covered with a single layer of jute netting, was the mulch used.

Preparation and application.--Seedbed preparation consisted of ripping all soils to a depth of 10 inches, and then harrowing several times with a spring-toothed harrow until the soils were friable and no large clods were present on the surface. Care was taken to insure that the treatments were applied uniformly and confined to the appropriate subplot area. A small seed spreader was used to apply fertilizer on appropriate subplots at the rate of 300 pounds per acre and the fertilizer was raked in manually. Seed mixtures then were applied to all plots at a rate of 25.5 pounds per acre and raked lightly. Mulch was applied at a rate of 2.5 tons per acre where appropriate, and the entire study site was packed down with a Brillion Culti-Packer.

Irrigation.--From May 18 through October 4, 1973, irrigation water was applied to the irrigated main plot at the rate of 1-1/2 inches per week in five daily applications of 0.3 inch. The sprinkler irrigation system was completely automated and provided a uniform application (uniformity coefficient 0.97).

The study site is approximately 200 feet from a coal test pit 80 feet deep, from which ground water was pumped and used as the irrigation water supply. This ground water is of low quality for irrigation purposes, principally because of the high sodium content (table 3). Other sources of irrigation water were considered impractical because of costs, transportation difficulties, or water right problems. The Decker Coal Company had been successfully using the pit water in short term irrigation projects.

During the second week of August, 2 months after irrigation started, soil analyses on the irrigated plot showed that conditions for plant growth were deteriorating. The pH near the soil surface was nearly 10, and exchangeable soil sodium had increased by 100 percent. To counteract this trend, calcium chloride was applied to the irrigated plot at the rate of 2,700 pounds per acre. The calcium chloride was applied over a 2-week period through the irrigation system as a saturated solution mixed 1:60 with the irrigation water.

Table 3.--*Results of analysis of ground water used for irrigation on the Decker coal mine*

pH	Total salts (Mmho/cm)	Other constituents (p/m)			
		Na	Ca	Mg	HCO_3
8.8	1,533	350	2.6	5.0	1,197

DATA COLLECTION

Two types of data were collected for each of the 144 subplots: (1) grass stand density, and (2) estimates of the dry weight grass production. During data collection, all measurements and counts were made on the interior 6- by 6-foot area of each subplot. This action separated subplot treatments with a buffer zone 2 feet wide.

Early in the growing season, seedling emergence was assessed by making grass seedling density estimates on the top-dressed plot and on the control plot only. All of the seedlings were counted on a randomly selected 10-square-foot area of each subplot.

Estimates of the dry-weight production of grass on each subplot were made during the first week of October 1973. Nondestructive sampling was imperative since future measurements are required. Therefore, the Neal capacitance meter, Model 18-1000, was used to estimate production (Neal and Neal 1973). To calibrate the capacitance meter, one of every six herbage plots (1 by 2 feet) read with the meter was clipped and the dry weight measured. The influence of weeds on the capacitance readings was a complicating factor; however, the weed effect was accounted for by clipping them separately from the grasses. The weight of weeds was excluded from all analyses reported here.

RESULTS

During the 1973 growing season, weather conditions were generally favorable for plant growth. From April through September, precipitation amounts were approximately 15 percent above the long-term mean. Average daily air temperature was slightly below normal. Therefore, for the Decker mine site, the weather during this first growing season can be characterized as cool and moist.

Figure 2 summarizes the grass production results. Generally the greatest yields came from the mixture of introduced grasses, which averaged 789 pounds per acre, and the smallest yields from the mixture of native grasses, which averaged 629 pounds per acre. However, the native grass mixture performed better than expected in the first growing season with a maximum production of 1,543 pounds per acre. Several of the more favorable treatments yielded native grass stands that would provide good erosion protection to the soil (fig. 3).

Data on both seedling emergence and dry weight production were analyzed for variance. A confidence level of 95 percent was used to determine significant differences.

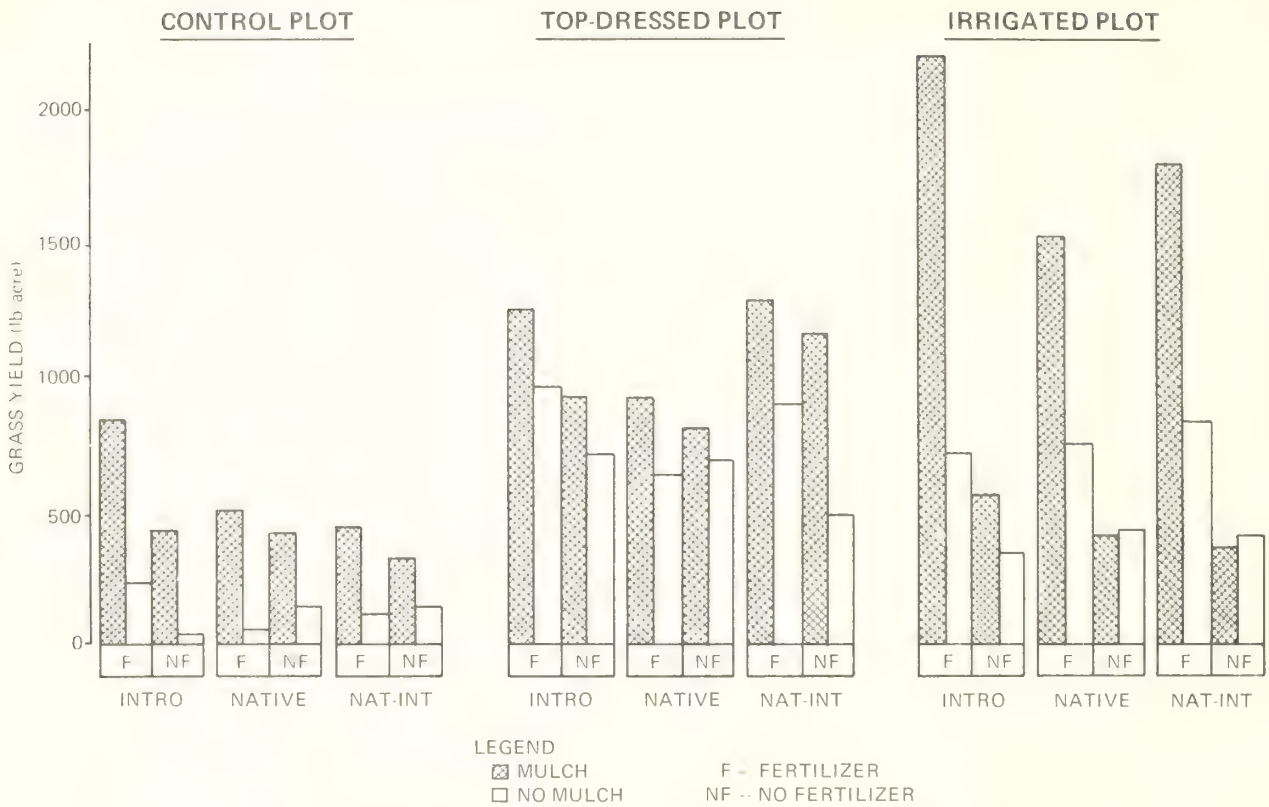

Figure 2.--Average dry-weight grass production, for each main plot by subplot treatments. INTRO, NATIVE, and NAT-INT are seed mixtures.

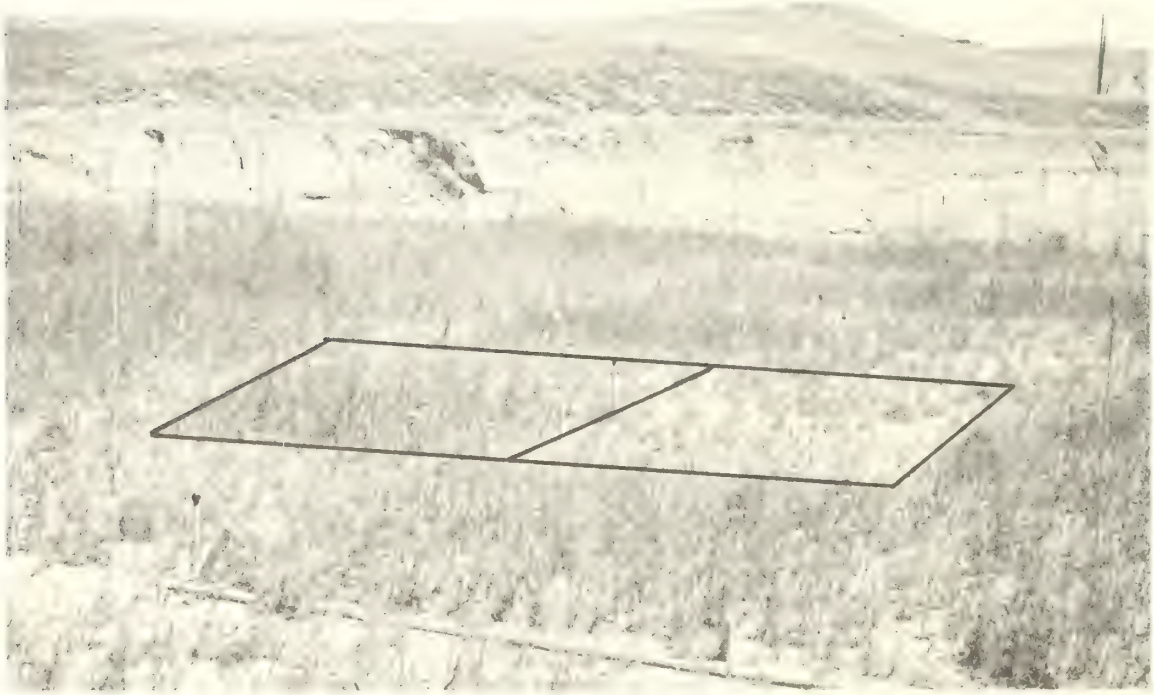

Figure 3.--View of a portion of the study site, October 1973. Irrigated subplots of native grasses are indicated. The subplot to the left was fertilized; the one to the right was not.

Control Plot--Seedling Emergence

Seedling emergence on the control plot was entirely satisfactory, regardless of subplot treatments. Seedling counts ranged from 11 to 22 per square foot; the average was 17 per square foot. The analysis of variance on the effects of seed mixture, mulch, and fertilizer showed:

1. There was a significant difference in seedling emergence due to grass mixture. The mixture of introduced grasses emerged best (22 per square foot) the native-introduced mixture next (19 per square foot) and the native mixture poorest (11 per square foot).

2. There was a significant difference in seedling emergence due to mulch. The average count on mulched plots was 21 per square foot as opposed to 14 per square foot on unmulched plots. The beneficial effect of mulch decreased in the following order: introduced grasses > native plus introduced grasses > native grasses.

3. There was no significant difference in seedling emergence due to fertilizer treatment; fertilized plots had 17 per square foot, and the unfertilized plots had 18 per square foot.

Control Plot--Grass Yield

As expected, the control plot produced less grass than either of the other main plots. The fertilized, mulched subplots produced the best stands and provided marginally acceptable grass cover. The relatively good stands of grass on the unfertilized, mulched subplots were not expected, and are unexplained. This effect will be monitored for several years to determine if it persists.

The analysis of variance on the dry-weight production data showed:

1. The mixture of introduced grass species gave significantly higher yields than either the native grass mixture or the native-introduced grass mixture. Yields from the latter two mixtures were not significantly different.

2. Mulch significantly increased the production of all grass mixtures.

3. The effect of fertilizer is modified by the effect of mulch. On unmulched subplots there was no fertilizer effect, but on mulched subplots fertilizer significantly increased production. The effect of fertilizer was not uniform for all grass mixtures, significantly increasing the production of the introduced grass mixture, but not of the other two mixtures.

Top-Dressed Plot--Seedling Emergence

Seedling counts on the top-dressed plot ranged from 10 to 19 per square foot: the average was 16 per square foot. These counts are sufficiently high to produce good grass stands. The analysis of variance on the effects of seed mixture, mulch, and fertilizer on seedling emergence showed:

1. There was no significant difference in seedling emergence between the native-introduced grass mixture (19 per square foot) and the introduced grass mixture (18 per square foot). The native grasses had significantly poorer emergence (10 per square foot) than did the other two.

2. There was a significant difference in seedling emergence due to mulch. The average count on mulched plots was 20 per square foot as opposed to 11 per square foot on unmulched plots. The beneficial effect of mulch decreased in the following order: introduced grasses > native plus introduced grasses > native grasses.

3. There was a significant interaction between fertilizer and mulch (the effect of fertilizer on seedling emergence depended on the mulch treatment). On unmulched plots, fertilizer had no effect. On mulched plots fertilizer decreased emergence from 21 to 19 per square foot.

Top-Dressed Plot--Grass Yield

Grass production on the top-dressed plot was generally satisfactory regardless of subplot treatments, the lowest production figure being 502 pounds per acre. Production differences among treatments were usually smaller than on the other main plots. The analysis of variance of the dry-weight production showed:

1. The two grass mixtures that contained introduced grass species produced significantly greater yields than did the native grass mixture.

2. Mulch significantly increased the production of all grass mixtures.

3. Fertilizer significantly increased the production of all grass mixtures.

Irrigated Plot--Seedling Emergence

Seedling emergence counts were not made on the irrigated plot. However, limited count data and visual estimates convinced the authors that seedling counts on the irrigated plot would produce results similar to the counts made on the control plot.

Irrigated Plot--Grass Yield

Among main plots, the irrigated plot produced the greatest average yields. Subplots that were fertilized and mulched produced 2,238, 1,813, and 1,543 pounds per acre for introduced, native-introduced, and native grass mixtures, respectively. In the absence of either mulch or fertilizer, yields showed a marked decrease. There were no indications that the use of low quality irrigation water (table 3) adversely affected yields during the first growing season. However, the irrigation water was a source of a great increase in exchangeable soil sodium, necessitating correction with calcium chloride.

The analysis of variance on production data for the irrigated plot showed:

1. There was no significant difference in yield due to the use of different grass mixtures.

2. Mulch significantly increased the production of all grass mixtures.

3. Fertilizer significantly increased the production of all grass mixtures.

DISCUSSION

This study was designed to test a broad spectrum of potential treatments to determine the minimum combination of different treatments necessary to provide an acceptable plant cover. These first-year results do not conclusively indicate the minimum combination; more time will be required for that. However, there are strong trends in the data that suggest which treatments may be most acceptable.

There are no indications that the raw overburden material had any adverse effects on either seed germination or seedling emergence. Seedling counts early in the growing season showed plentiful vegetation on all subplots. This result is partially attributed to thorough seedbed preparation and packing the seedbed after sowing.

On the basis of dry-weight production, several treatments yielded grass stands capable of adequately protecting the spoil material against either water or wind erosion. The greatest yields were on irrigated subplots that were both fertilized and mulched. However, this treatment cannot as yet be recommended for two reasons: (1) continued irrigation with the present water supply will probably create strongly adverse soil conditions that will require correction, and (2) there is no information as yet on the consequences of stopping irrigation. These limitations also apply to irrigated plots that were fertilized but not mulched. The unfertilized irrigated subplots yielded rather poor stands and do not, at this time, appear to offer a desirable alternative.

All of the subplots located on the top-dressed soil yielded acceptable stands. Fertilizer had some positive effect, though not as large as expected. The principal objection to top-dressing, aside from cost considerations, will probably be the presence of weed seeds in the topsoil. On the average, over the entire top-dressed plot, only 47 percent of the total yield was in desirable grass species; the rest was in weeds, principally summer cypress (*Kochia scoparia*), Russian thistle (*Salsola kali*), and Japanese brome (*Bromus japonicus*). If top-dressing is practiced, some type of weed control program seems desirable. Generally, the control plots did not produce adequate grass stands in the first year. An exception may be the control plots that are both fertilized and mulched, but these plots are only marginally acceptable.

Grass yield means may be grouped according to grass mixture and ranked by treatment (fig. 4). This grouping combines the results from control, irrigated, and top-dressed plots and is useful for making comparisons among the treatments for each grass mixture. For instance, none of the grass mixtures on the control plot produced 500 pounds per acre of dry matter without both fertilizer and mulch. Except for the irrigated plots that were mulched and fertilized, the top-dressed plots generally yielded the greatest grass weights. According to these first-year results the top-dressing of mine overburden, regardless of mulch or fertilizer, appears to be a highly desirable revegetation practice.

In each seed mixture the wheatgrasses dominated the dry-weight production. Generally, wheatgrass seedlings were identified only as *Agropyron* spp. However, the slender wheatgrass plants were exceptionally vigorous and many produced seed in the first growing season. Smooth brome was a notable component of both the introduced and native-introduced grass mixtures, but usually did not set seed. In the native grass mixture, sideoats grama is an important stand component. More complete species information will be collected as the study progresses.

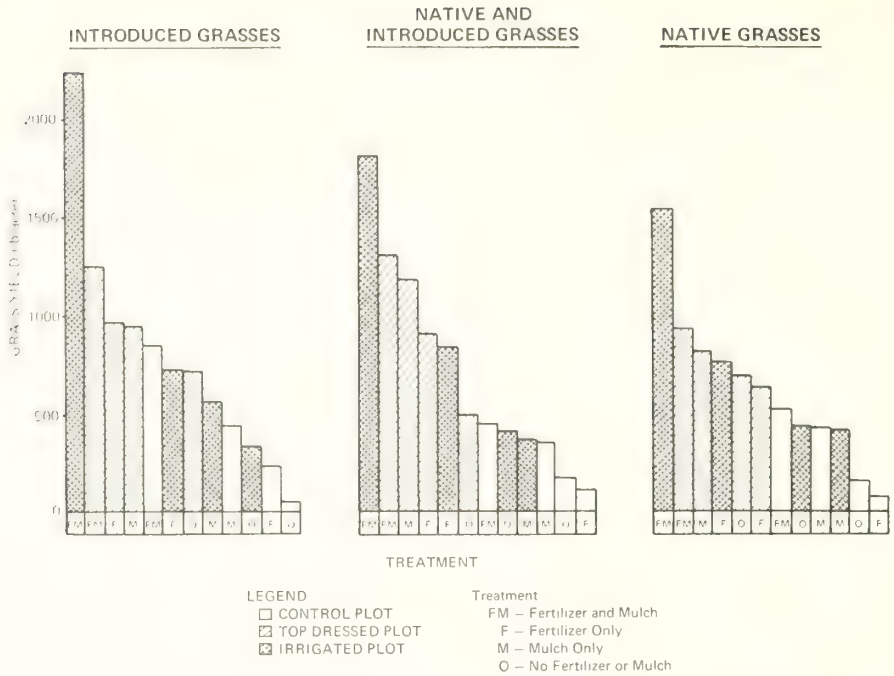

Figure 4.--Mean dry-weight grass production by treatment, ranked within grass mixtures.

These data do not give a strong basis for choosing between the three grass mixtures under study. Clearly, the mixture of introduced grasses has outproduced the other two mixtures. However, the long-term considerations favor the native species as being most likely to hold the site in spite of drought, insects, and disease. Also, some native grasses have responded very favorably to some treatments. Probably the major disadvantage of using a mixture of only native grass species is the almost complete commercial unavailability of native grass seed. This may be a serious limitation to large-scale revegetation efforts. It would probably be a mistake to completely ignore the many desirable species of introduced grasses in the revegetation of surface-mined areas.

It is important to recognize that this study concerns the revegetation of one type of mine overburden material. At the Decker mine there are other overburden materials that vary in both chemical and physical properties from the one under study. Other mine sites have other types of overburden material.

LITERATURE CITED

Brown, R. W.
1971. Distribution of plant communities in southeastern Montana badlands. Am. Midl. Nat. 85:458-477.

Hodder, R. L., and B. W. Sindelar.
1972. Coal mine land reclamation research, location - Decker, Montana. Mont. State Univ. Agric. Exp. Stn., Res. Rep. 21, Bozeman, Mont.

Neal, D. L., and J. L. Neal.
1973. Uses and capabilities of electronic capacitance instruments for estimating standing herbage. J. Br. Grassland Soc. 28:81-89.

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Soil Characteristics Influencing Lodgepole Pine Regeneration Near West Yellowstone, Montana

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Soil Characteristics Influencing Lodgepole Pine Regeneration Near West Yellowstone, Montana

James E. Stermitz, Murray G. Klages, and James E. Lotan

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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401
Roger R. Bay, Director

THE AUTHORS

JAMES E. STERMITZ runs a family ranch at Cinnabar Basin of the Yellowstone River, Montana. Mr. Stermitz received a Bachelor of Science degree, with honors, in soils from Montana State College (now Montana State University) in 1962 and an M.S. degree in soils in 1967.

DR. MURRAY G. KLAGES is professor of soils at Montana State University. He is currently conducting research in clay mineralogy with the Agricultural Experiment Station and teaches courses in clay mineralogy, soil management and the environment, and soils analysis.

Dr. Klages received his B.S.A. degree in chemistry from Ontario Agricultural College in 1947, an M.S. degree in soils from the University of Wisconsin in 1949, and a Ph.D. in soil chemistry from Purdue University in 1955. He conducted postdoctoral studies in clay mineralogy in 1967-1968 at Michigan State University in East Lansing, Michigan.

JAMES E. LOTAN is Program Manager for the Intermountain Forest and Range Experiment Station in Missoula, Montana. He heads up a major research, development, and applications effort designed to improve on-the-ground fire management and to integrate fire considerations in the multiple use planning process.

Previously, he served as Project Leader of the Northern Rocky Mountain Forest Ecosystems research work unit in Bozeman, Montana. He has conducted research in lodgepole pine silviculture for 13 years and has contributed a number of articles on lodgepole pine management.

Dr. Lotan, who holds a B.S. degree from Louisiana State University, received his graduate training in forestry at the University of Michigan.

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ABSTRACT

In direct seeding from soils of volcanic origin, seedbed preparation treatments affected germination and first-year survival insignificantly, compared to site differences. A strong positive relation between survival and the amount of silt plus clay in the soil was identified. Available potassium and total nitrogen had a negative influence, attributable to poor seed-soil contact and competition for moisture on the more fertile sites. The three soil properties explained 93 percent of the variance in seedling survival. A response surface for the three soil properties was developed, as an aid in predicting survival.

INTRODUCTION

In Montana, natural regeneration of lodgepole pine commonly results in overstocking. For reproduction of clearcut stands, forest managers generally can rely on seed stored in serotinous cones in the logging slash. On some cuttings near West Yellowstone, Montana, and Island Park, Idaho, however, stands of natural regeneration were inadequate, and studies were begun in 1961 to determine the causes of failure. Direct seeding trials varied in results (Lotan 1964). The more intensive seedbed treatments gave the highest germination and survival for the first year, but subsequent results varied with soils.[1] Both germination and survival after 5 years were higher on medium-textured soils in the Island Park area than on obsidian sands and gravels near West Yellowstone. The principal cause of first-year mortality was drought.

Success in forest regeneration is of course highly dependent on climate and soils. If the relation between seedling establishment and measurable soil properties could be defined, seeding rates could be based on reliable predictions of stand density. Then costs of regenerating an area might be predicted, even before timber is harvested. Also, the most suitable seedbed treatment could be more easily determined.

This study was designed to further explore the effect of physical and chemical properties of soils on seedling survival. Several moisture-conserving seedbed treatments were also tested. From the test results, correlations were sought that might serve as predictors of regeneration success in the study area.

STUDY AREA AND EXPERIMENTAL METHODS

The West Yellowstone area lies on the western edge of a Pliocene plateau that collapsed to form a caldera 30 miles in diameter (Hamilton 1960). During late Quaternary, viscous rhyolite flowed into the caldera. Pliocene rhyolites form a ring bounding the Quaternary flows. Much of the ring is covered by flows composed of brecias of black obsidian and unconsolidated matrix of sandlike glass shards. Similarly, the Island Park Basin in Idaho is a caldera 18 miles in diameter rimmed by rhyolite and filled with basalt.

Water has played an undetermined role in the formation of soils in the area. Most of the soil is a loamy sand composed of angular or slightly rounded obsidian fragments and rhyolite, undoubtedly transported by water from the rim of the area. A unique feature is the numerous ridges of fine sand and silt that extend into the basin from the edges. Two large streams, the South and Main Forks of the Madison River, cross the area, and large sections of stream-deposited sands and gravels are exposed along their banks.

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[1]Subsequent results are data on file, Forestry Sciences Laboratory, Bozeman, Montana.

Soil Characteristics

In 1964, a preliminary study was made of soils in this area to determine causes of poor germination and survival. Pits were dug and soils were examined in locations in the Hebgen Lake Basin (near West Yellowstone) numbered 1 to 8 in figure 1. Root concentration and structural development were greatest in the upper 13 cm. Soil material became noticeably more gravelly at about 50 cm.

Soil profile descriptions are given in Appendix I for site 1 (representing general soil conditions in the major part of the alluvial basin), site 6 (representing what may be somewhat less favorable soil conditions), and site 8 (representing favorable soil conditions for forest).

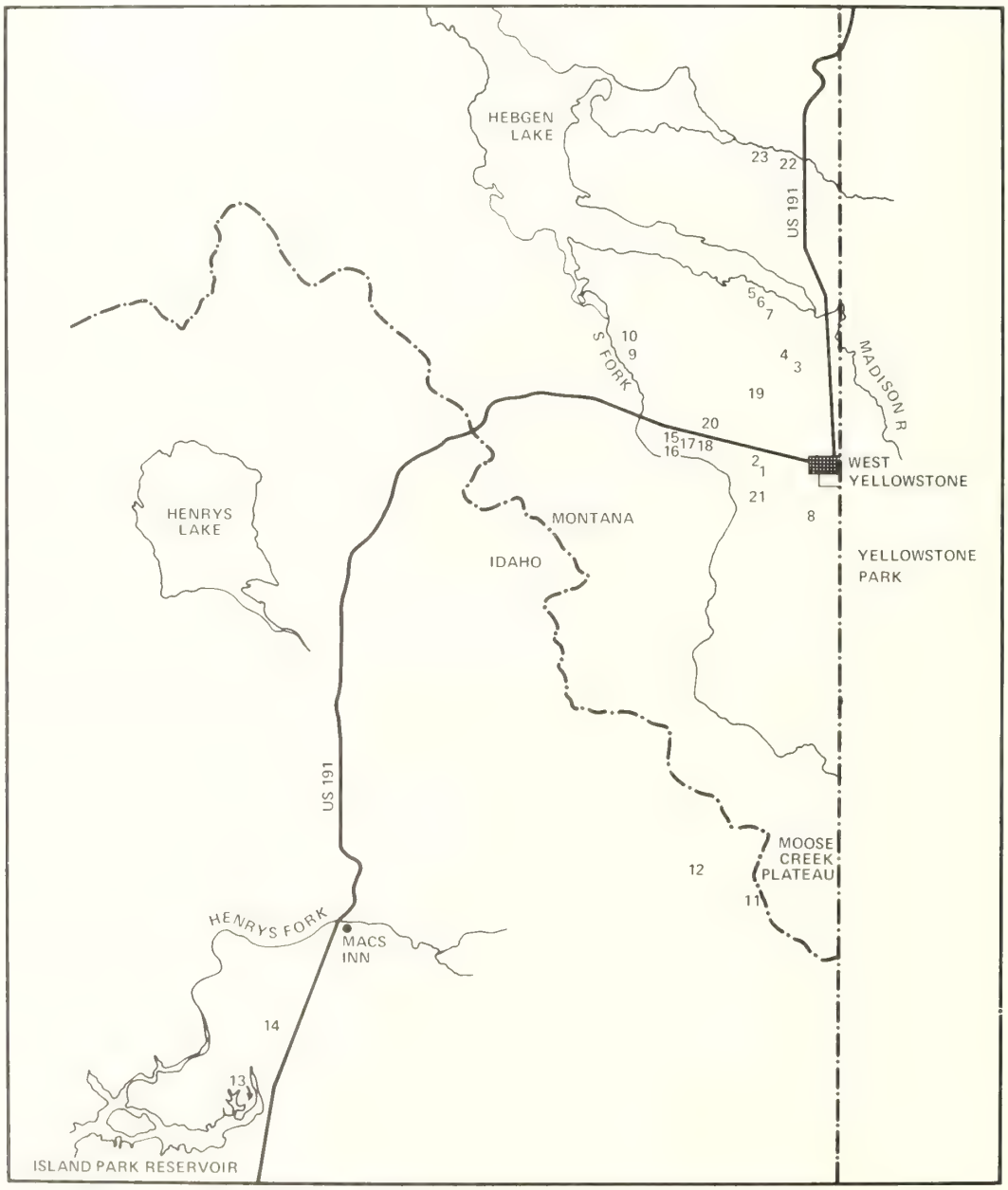

Figure 1.--Sites of soil profile pits and direct seeding trials.

Seeding Trials

Seeding trials were conducted at 19 locations, including four of the preliminary soil profile study sites. (No trials were conducted at profile sites 2, 3, 5, and 7. Fifteen of the sites were in the West Yellowstone area; two (13 and 14) at Island Park; and two (11 and 12) at Moose Creek Plateau (fig. 1). All sites were at elevations of about 2,000 m except sites 11 and 12, which were at 2,450 m.

Conditions varied on the test locations. The surface texture at eight sites were gravelly sandy loam over sand and gravel at 30 to 46 cm. At two other sites, texture was similar, but at one of these the loam was deeper over sand and gravel and at the other it was somewhat finer in the surface 35 cm. Five of the six remaining sites had deep loam, silt loam, and fine sandy loam textures, sometimes getting more clayey with depth. One site had surface horizons of sandy loam and fine sandy loam overlying sand and gravel at 23 cm. All but two sites were well drained. Site 8 was moderately well drained, and site 23 was poorly drained. Four sites were in natural openings in the forest; the others were in clearcut areas, several of which showed good regeneration in the vicinity of the test plots. The soil surface at site 13 had a dense sod mat of live and dead sedge roots.

Treatments

Each trial site was seeded in a randomized block design with three replications of four treatments: (1) spading, (2) spading plus application of a liquid petroleum mulch, (3) spraying with Dalapon, an herbicide, and (4) control. Plots were 1 m^2 and were surrounded by a buffer zone 30 cm wide. Spading and spraying with Dalapon were carried out between August 22 and September 8, 1966.

Lodgepole pine seed, treated with 17.5 percent anthraquinone and 2.5 percent Endrin (clean, untreated seed basis), was broadcast sown on October 12 and 13, 1966. Each plot received 375 total seeds with 55 percent viability. In addition, to check for rodent losses, 25 seeds covered with a 1/4-inch mesh wire cover and 25 seeds left uncovered were planted on a small cultivated area near the plots at each site.

The liquid petroleum (asphalt) mulch (Soil Gard, a product of Alco Chemical Corporation) was applied in May and June 1966. The mulch was diluted 1:5 with water and applied with a hand sprinkling can at a rate of about 4 liters (1 gal) of concentrated mulch per 20 m^2.

Seedling counts were made monthly; each seedling was marked with colored plastic toothpicks (a different color for each examination). The first count was made June 19-20, 1967, and final counts were made September 19-21, 1967. Mortality was noted at the monthly count.

Soil Analysis

The soil variables measured included a wide range of characteristics related to fertility and water-holding capacity. Available water-holding capacity was thought to be a major influence on tree growth on these soils. Earlier measurements on the eight sites for which soil profiles had been described in 1964 indicated that two sites had a high available water content. At that time, tree growth in the vicinity of the three sites suggested that they were more favorable than the other locations studied.

Soil samples for fertility measurements were taken from each trial site at depths of 0 to 15 cm and analyzed for pH of a saturated paste, for total nitrogen by the micro-Kjeldahl technique, for available phosphorus by the sodium bicarbonate method (Olsen and others 1954), and for available potassium by extraction with ammonium acetate (Jackson 1958). Soil samples for physical and chemical characterization were

taken from each trial site at depths of 0 to 7.5, 7.5 to 15, and 15 to 30 cm. They were air-dried, weighed, and screened through a 2-mm sieve (the fine earth fraction passed through the sieve). The fine earth fractions were analyzed for sand, silt, and clay by hydrometer (Bouyoucos 1936), using sodium hexametaphosphate to disperse the soil. Specific surface was determined with orthophenanthroline (Lawrie 1961). Percent water at 15 atmospheres tension was determined on a pressure membrane (Richards 1965). Organic matter was determined by the Walkley-Black method as described by Jackson (1958), using chromic acid and heat of dilution of sulfuric acid. Exchangeable cations were extracted with neutral normal ammonium acetate (Bower and others 1952). Exchangeable potassium was determined with a flame photometer and calcium plus magnesium by versenate titration (Cheng and Bray 1951). Exchangeable hydrogen was replaced by sodium acetate at pH 8.2 and measured by titration to the phenolphthalein end point. Undisturbed soil cores were taken at the same three depths from eight trial sites considered to be representative. Capillary and noncapillary porosity were measured by means of a Leamer and Shaw (1941) tension table, at 50-cm tension. Bulk density was calculated from the ovendry weight of the cores, and particle density from the volume of water displaced in a graduated cylinder by the soil in the cores.

RESULTS

Seedbed Treatments

Lodgepole pine is frequently seeded in the fall because it is difficult to get to sites in the spring. During winter, seeds are lost to birds and rodents, and are removed from the planting site by wind and by soil and snow movement. Although seed used in test plots was treated to repel birds and rodents, much was lost, especially on sites in natural forest openings (such as sites 6, 9, and 10). Animals, presumably mice, bit small holes in the seedcoat and removed seed contents. Several white-footed deer mice were live-trapped and later fed lodgepole pine seed treated with the repellent. They would not eat freshly treated seed, but if seeds were rinsed with water, the mice readily ate them. Apparently the anthraquinone-Endrin repellents are not entirely effective in repelling rodents if seed remains on site over winter. On the sites affected, where seeds were protected by wire screens, average emergence was 51 percent, whereas it was only 9 percent for those exposed to rodents.

Germination extended over a period of four months (table 1). Some germination was observed near the end of May when, except for those on the Moose Creek Plateau, test sites were free of snow (even though deep snowbanks surrounded the openings). Conditions are usually favorable for germination upon snowmelt in the area. Climatological data from the West Yellowstone Weather Station indicate a maximum temperature of 78°F on May 22. This agrees with previously published statements that temperature fluctuation from 52° to 72°F is conducive to germination (Bates 1930). In these tests, more germination occurred in July than in earlier experiments reported by Lotan (1964).

Table 1.--*Periodicity of germination of lodgepole pine seedlings, June-September 1967, near West Yellowstone, Montana*

Sites	Germination			
	June	July	August	September
West Yellowstone No. 1, 4, 6, 8-10, 15-23	62	34	4	0.2
Moose Creek Plateau No. 11, 12	--	34	56	10.0
Island Park No. 13, 14	45	46	8	--

As might be expected, total number of seeds germination was slightly higher on spaded plots than on control plots (table 2). Results of spade-plus-mulch, and spray treatments, were intermediate. Analysis of variance indicated that seedbed treatments were not significantly effective in increasing survival at the end of the first season. Spading, which removed all competing vegetation, resulted in the highest survival (table 2). The spade-plus-mulch treatment was expected to be more effective. The mulch was applied in late May; its application a month later, after the rainy season and before dry weather caused moisture losses, might have been more successful.

Spraying also failed to increase survival noticeably. Field observations indicated that spray applied the fall before seeding was effective in retarding growth of grasses and sedges in the following season. Spraying probably had a retarding effect on germination when the grass or sedge was particularly thick, however; the dead grass formed a mat that appeared to prevent seed from reaching the soil surface.

Site Influences

Germination and survival were both significantly better on five sites (8, 11, 12, 1, and 23--see table 2). All but one of these sites had medium-textured soils. Site 3, the exception, was poorly drained. The only medium-textured soil with poor germination and survival was 13. It had a dense sod mat and, apparently, a high rodent population; germination was good when seeds were protected from rodents. Survival data showed an overall statistically significant interaction between site and treatment effects; that is, treatments were not equally effective at all sites. Spading was apparently more effective on medium-textured soils.

In specific soil characteristics, the sites varied widely. Values for all characteristics measured are given in Appendix II. The study sites would be considered low in available nitrogen and potassium, and medium to high in available phosphorus for most agricultural crops, but were within limits set by Wilde (1964) for conifer establishment. Specific requirements of lodgepole pine seedlings have not been established. The pH of all sites was close to 6.0, which is also within the recommended range. Analysis of variance indicated that physical and chemical soil properties varied significantly between sites and depths sampled.

Table 2.--*Emergence and survival of lodgepole pine seedlings, by seedbed treatment*

Site	Treatment				
	Control	Spade	Spade + Mulch	Spray	Mean
	SEEDLINGS EMERGING (AV./M^2)				
West Yellowstone					
1	11.0	21.0	13.0	28.7	18.4
4	15.3	10.0	7.0	15.0	11.8
6	1.0	1.0	.7	1.7	1.1
8	15.3	67.3	61.7	29.3	43.4
9	6.7	3.7	1.7	5.3	4.3
10	1.7	3.3	1.3	2.0	2.1
15	2.3	7.3	2.7	5.3	4.4
16	7.7	11.0	6.0	14.3	9.8
17	2.7	7.0	4.0	2.7	3.8
18	1.0	4.3	3.0	5.7	3.5
19	2.0	5.3	1.3	2.0	2.7
20	11.0	13.3	8.7	9.0	10.5
21	25.0	36.3	40.3	48.3	37.5
22	.3	5.0	7.3	5.7	4.6
23	56.3	36.3	20.3	75.3	47.1
Moose Creek Plateau					
11	14.7	29.0	16.0	16.7	19.1
12	18.0	33.0	21.0	15.0	21.8
Island Park					
13	4.0	6.3	10.3	2.7	5.8
14	15.0	33.7	15.7	9.3	18.4
Mean	11.1	17.6	12.7	15.4	
	SEEDLINGS SURVIVING (AV./M^2)				
West Yellowstone					
1	.0	1.3	2.0	.3	.9
4	12.7	6.3	6.3	9.3	8.7
6	.0	.0	.3	.7	.2
8	11.3	43.0	41.7	23.7	29.9
9	.0	1.3	.0	.0	.3
10	.0	.7	.0	.3	.2
15	.3	.7	.0	1.7	.7
16	.0	.7	1.3	.0	.5
17	2.0	3.3	2.0	.7	2.0
18	.0	.0	.3	.0	.1
19	.0	.7	.3	.3	.3
20	1.7	1.7	2.3	2.3	2.0
21	22.0	35.7	34.3	43.3	33.8
22	.0	.7	4.7	.3	1.4
23	53.7	27.0	12.7	65.3	39.7
Moose Creek Plateau					
11	13.3	26.7	14.0	16.0	17.5
12	14.0	28.7	18.7	13.0	18.6
Island Park					
13	2.0	3.7	6.3	1.3	3.3
14	2.7	9.7	4.3	3.7	5.1
Mean	7.1	10.1	8.0	9.6	

The large variation among sites made a screening process of simple and multiple linear regressions necessary to identify soil variables that most effectively predicted seedling survival. Those finally chosen as relatively simple variables that consistently gave high correlations were levels of total nitrogen (percent), available potassium (p/m), and silt plus clay (percent), all measured to a depth of 15 cm. The linear regression equations for mean survival (S) in seedlings per square meter were as follows:

$$S = 0.60 \times \text{percent silt plus clay} - 11.4 \quad (r^2 = 0.414)$$

$$0.88 \times \text{percent silt plus clay} - 230 \times \text{percent nitrogen} - 2.2 \quad (R^2 = 0.668)$$

$$0.63 \times \text{percent silt plus clay} - 318 \times \text{percent nitrogen} + 0.11 \times \text{p/m potassium} - 5.7 \quad (R^2 = 0.732)$$

In this calculation, mean survival data for all treatments were used to achieve the greater confidence possible when survival is measured over a larger number of plots.

To further define the relationships of the three variables, a response surface (fig. 2) was developed using techniques described by Jensen (Jensen and Homeyer 1970, 1971; Jensen 1973). The mathematical functions used in fitting this surface are given in Appendix III. These models are of particular benefit for use in the larger information systems. The same relationships are shown in table 3 for use where adequate data-processing capabilities are not available. The data may be interpolated in linear fashion for small differences in table 3.

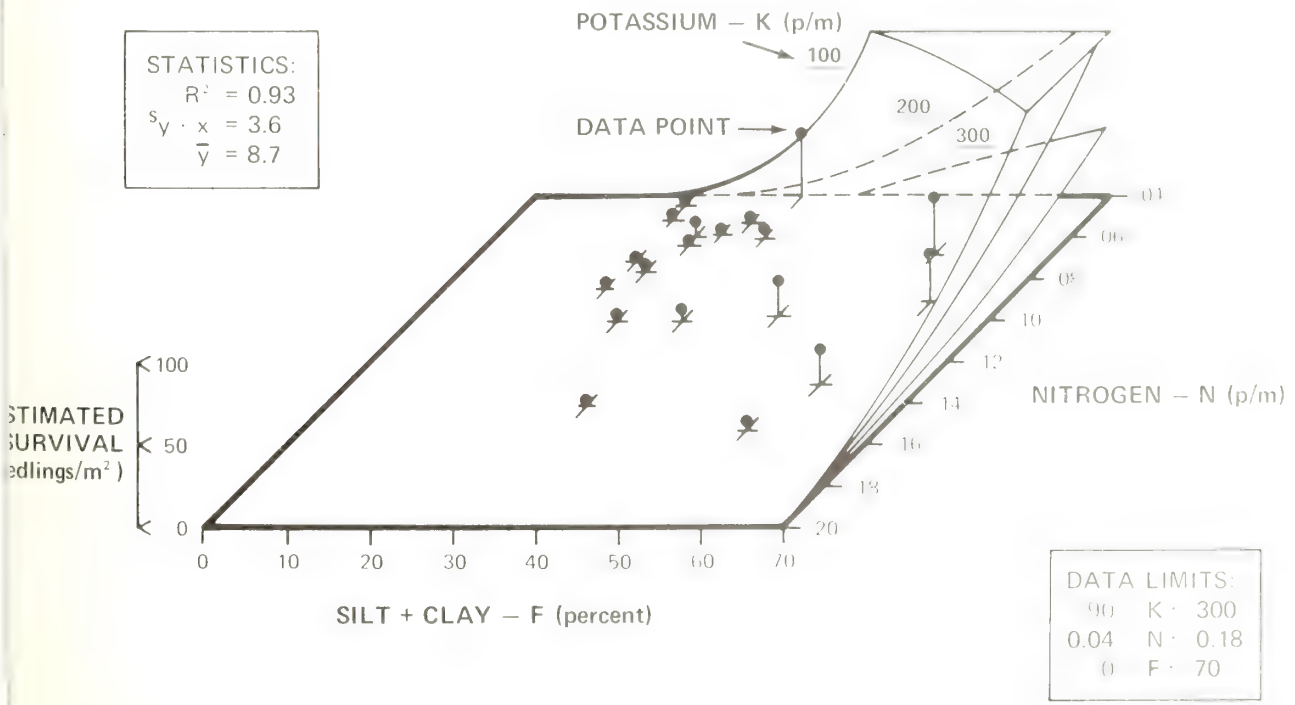

Figure 2.--Relation of [illegible] to silt plus clay fraction, total nitrogen, and available potassium (p/m) in the surface 15 cm deep. [illegible] 100 exists here and should be included in the computer model.

Table 3.--*Estimated survival of lodgepole pine, in seedlings per square meter, at end of summer, according to silt plus clay fraction, total nitrogen, and available potassium, based on data from tests near West Yellowstone, Montana*

Potassium (p/m)	Nitrogen (p/m)	Seedlings surviving when percent silt + clay is ...						
		10	20	30	40	50	60	70
100	0.04	0	4	25	94	200	200	[1]200
	.06	0	1	6	23	59	110	160
	.08	0	1	4	14	36	68	100
	.10	0	0	3	11	27	50	74
	.12	0	0	2	7	19	35	52
	.14	0	0	1	5	12	22	32
	.16	0	0	1	2	6	12	17
	.18	0	0	0	1	2	4	6
	.20	0	0	0	0	0	0	0
200	.04	0	1	6	19	45	79	112
	.06	0	1	4	14	32	56	80
	.08	0	1	3	11	25	44	62
	.10	0	0	2	8	18	33	46
	.12	0	0	2	6	13	23	32
	.14	0	0	1	4	8	14	20
	.16	0	0	1	2	4	8	11
	.18	0	0	0	1	1	2	4
	.20	0	0	0	0	0	0	0
300	.04			0	4	17	34	42
	.06			0	3	14	27	34
	.08			0	2	11	21	27
	.10			0	2	8	16	20
	.12			0	1	6	11	14
	.14			0	1	4	7	9
	.16			0	0	2	4	5
	.18			0	0	1	1	2
	.20			0	0	0	0	0

[1]Computer truncation of the relation at a maximum of 200 is shown. A practical maximum is probably near 100.

DISCUSSION

Total nitrogen is a measure of organic matter in the soil. It reflects the amount of vegetation present in the past and indicates the probable growth of grass and weeds that might compete with the seedlings. Probably, the negative relation of nitrogen to survival is due partly to poor seed-to-soil contact on sites with high organic accumulation and partly to greater competition for moisture on the more fertile sites. The negative effect of available potassium is more difficult to explain than that of nitrogen but may have a similar basis.

Significant differences among treatments were not evident, but differences among the nonreplicated sites were significant. If soil variables are accounted for, however, comparison of least squares coefficients (see Appendix III) shows that results of spraying and spading treatments were more affected by soil variables than were the control and mulched plots. The spading and spraying treatments removed vegetation that caused seed and seedling losses in the control plots. Mulching was apparently less successful, but the effects of mulch are unclear in field studies such as this. The results of these tests suggest the relative effectiveness of the three treatments for natural regeneration or direct seeding when climate and vegetation are similar to those in the study area. The effectiveness of seedbed treatment would probably be more pronounced, however, in seasons with less precipitation than was encountered here. In addition, rodent populations have a great influence on results, particularly when seed supply is marginal.

SUMMARY

Preliminary studies in the West Yellowstone area found soils to be formed primarily from obsidian and rhyolite sandy and gravelly materials. These studies suggested that the low water-holding capacity associated with coarse volcanic soils is a strong influence on seedling establishment.

Direct seeding trials were conducted on soils with a wide range of physical and chemical properties. Three seedbed treatments wre incorporated into the trials: spading, spading plus mulch, and spraying with herbicide.

Large numbers of seed were lost through rodent damage. Seed treatment as used here evidently becomes ineffective in repelling rodents after it has been washed with rain or snow.

Weather stations located in the experimental area indicated an unusually wet spring the year this experiment was conducted. Seedbed treatments did not exhibit the pronounced effect on seedling survival that might be experienced in a drier year. Spading proved most effective in increasing the number of seedlings surviving the first summer. Asphalt mulch was not successful.

Seedling survival varied markedly with soil characteristics. Screening by means of simple and multiple regressions indicated that soil suitability for direct seeding could be evaluated in that area by analysis for silt plus clay content, total nitrogen, and available potassium. Survival after the first season was positively correlated with silt plus clay and negatively correlated with nitrogen potassium. Together, these three factors accounted for 93 percent of the variance in survival after the first summer. A mathematical function for the relationship was used to develop a response surface for computer prediction.

LITERATURE CITED

Bates, C. G.
1930. The production, extraction, and germination of lodgepole pine seed. U.S. Dep. Agric. Tech. Bull. 191, 92 p.

Bouyoucos, G. J.
1936. Directions for making mechanical analysis of soils by the hydrometer method. Soil Sci. 42:225-230.

Bower, C. A., R. F. Reitmeier, and M. Fireman
1952. Exchangeable cation analysis of saline and alkali soils. Soil Sci. 73: 251-261.

Cheng, K. L., and R. H. Bray
1951. Determination of calcium and magnesium in soil and plant material. Soil Sci. 72:449-458.

Hamilton, W.
1960. Late Cenozoic tectonics and volcanism of the Yellowstone region, Wyoming, Montana, and Idaho. Billings Geol. Soc. 11th Annu. Field Conf., p. 92-105.

Jackson, M. L.
1958. Soil chemical analysis. 408 p. Prentice-Hall. Englewood Cliffs, N. J.

Jensen, C. E.
1973. Matchacurve-3, multiple-component and multidimensional mathematical models for natural resource models. USDA For. Serv. Res. Pap. INT-146, 42 p.

Jensen, C. E., and J. W. Homeyer.
1970. Matchacurve-1 for algebraic transforms to describe sigmoid- or bell-shaped curves. USDA For. Serv. Intermt. For. & Range Exp. Stn., 22 p.

Jensen, C. E., and J. W. Homeyer
1971. Matchacurve-2 for algebraic transforms to describe curves of the class X^n. USDA For. Serv. Res. Pap. INT-106, 39 p.

Lawrie, D. C.
1961. A rapid method for the determination of approximate surface areas of clays. Soil Sci. 92:188-192.

Leamer, R. W., and B. Shaw
1941. A simple apparatus for measuring noncapillary porosity on an extensive scale. J. Am. Soc. Agron. 33:1003-1008.

Lotan, James E.
1964. Initial germination and survival of lodgepole pine on prepared seedbeds. USDA For. Serv. Res. Note INT-29, 8 p.

Olsen, S. R., C. V. Cole, F. Watanabe, and L. A. Dean
1954. Phosphorus in soils by extraction with sodium bicarbonate. U.S. Dep. Agric. Circ. 939.

Richards, L. A.
1965. Physical condition of water in soil. *In*: C. A. Black et al., (ed.), Methods of soil analysis, part I, Agronomy, 9, p. 128-152. Am. Soc. Agron., Madison, Wisc.

Wilde, S. A.
1964. Soil standards for planting Wisconsin conifers. J. For. 64:389-391.

APPENDIX I

Soil Profiles

Site 1

Location: 75 m northwest of the weather station near Lotan's plot in cutover area. NE 1/4, sec. 32, T. 13 S., R. 5 E.

0-5 cm A_1 — 10 YR 3/2 gravelly sandy loam; weak fine granular; friable; many medium and fine roots; porous; loam material coating the sand and gravel; pH 6.0; clear wavy boundary.

5-13 cm B_{21} — 10 YR 3/3 sandy loam; weak fine granular; friable; many medium and fine roots; porous; pH 5.7; clear boundary.

13-25 cm B_{22} — 10 YR 4/3 gravelly sandy loam; single grain; loam material coating sand and gravels; porous; abundant obsidian; pH 5.6; clear wavy boundary.

25-35 cm C_1 — Variegated gravel and sand (obsidian and rhyolite); few roots; pH 5.9.

35-55 cm C_2 — Same as above except increase in obsidian gravels; pH 6.0.

55-81 cm C_3 — Gravels are larger than in above horizons; pH 6.0.

Site 6

Location: In sagebrush. NE 1/4, sec. 8, T. 13 S., R. 5 E.

0-5 cm A_1 — Very dark grayish brown 10 YR 3/2 gravelly sandy loam; weak fine granular; friable; numerous medium and fine roots; many gravels at surface; pH 6.2.

5-20 cm B_{ir2} — Dark brown 10 YR 3/3 gravelly loam; weak fine granular; friable; many medium and fine roots; pH 6.2; clear wavy boundary.

20-38 cm B_{ir3} — Dark grayish brown 10 YR 4/2 - 3/3 gravelly loamy sand; single grain; firm; common medium roots; pH 6.3; gradual boundary.

38-76 cm IIC — Variegated gravel and sand; single grain common and medium roots; obsidian gravel increase below 65 cm; pH 6.6.

Site 8

Location: In lodgepole pine strip north of area reseeded by helicopter just south of pulpwood camp. NW 1/4, sec. 3, T. 14 S., R. 5 E.

0-15 cm A_1 10 YR 3/2 silt loam; moderate medium granular; friable; many medium and fine roots; pH 5.7; clear wavy boundary.

15-35 cm B_{21} 10 YR 4/2 silt loam; moderate medium platy; friable; few medium roots; pH 6.1; abrupt boundary.

35-48 cm B_{22} 10 YR 5/2 with 5/4 common distinct mottles; silt loam; firm; coarse prisms breaking to moderate to medium blocky; pH 6.1; abrupt smooth boundary.

48-66 cm IIC_1 10 YR 4/2 and 5/2 clay loam; weak fine blocky; firm, sticky and plastic; pH 5.8; abrupt boundary.

66-100 cm IIC_2 10 YR 5/4 sticky clay--auger sample; pH 6.4.

100+ cm $IIIC_3$ 7.5 YR 4/4 clay; pH 6.7.

APPENDIX II

Soil Characteristics

Table 4.--*Soil fertility measurements, 0 to 15 cm deep, on test sites near West Yellowstone, Montana*

Site	pH	Total nitrogen	Available phosphorus	Available potassium
		Percent	*(p/m)*	*(p/m)*
1	5.7	0.062	13.0	145
4	5.7	.059	7.2	108
6	6.3	.141	8.5	243
8	5.7	.089	19.6	278
9	5.9	.084	11.7	153
10	5.9	.101	9.0	208
11	5.5	.131	41.0	205
12	5.6	.098	24.8	188
13	5.6	.153	20.1	245
14	5.5	.102	10.5	218
15	6.0	.071	5.9	108
16	6.0	.076	9.2	130
17	5.9	.058	11.2	150
18	5.7	.050	8.7	115
19	6.1	.063	5.8	98
20	5.8	.053	7.6	118
21	5.7	.068	16.8	223
22	6.1	.043	6.0	95
23	5.7	.039	8.5	163

Table 5.--*Physical and chemical properties of the soil on test sites near West Yellowstone, Montana*

Site	Depth	Fine earth	Mechanical analysis			Specific surface	Water at 15 atm	Organic matter	Exchangeable cations		
			Sand	Silt	Clay				K	Ca+Mg	H
	cm	*Percent*				m^2/g	*Percent*		*meq/100g*		
1	0-7.5	78	67.3	24.5	8.2	39.0	7.1	4.0	0.52	5.58	3.12
	7.5-15	79	66.8	23.5	9.7	38.4	5.3	1.2	.34	4.01	2.28
	15-30	75	75.8	16.0	8.2	27.1	4.3	.29	.27	3.16	1.69
4	0-7.5	67	75.7	16.9	7.4	29.3	7.7	3.1	.44	4.51	3.08
	7.5-15	69	76.2	16.4	7.9	27.2	3.6	.54	.24	2.94	1.14
	15-30	71	70.0	20.0	10.0	22.6	3.8	.31	.23	3.52	1.09
6	0-7.5	60	67.8	25.3	6.9	41.7	10.8	4.8	.74	8.68	2.37
	7.5-15	51	68.9	23.2	7.9	29.2	7.9	2.4	.52	5.99	1.46
	15-30	49	75.4	16.8	7.8	22.5	5.1	.71	.41	5.57	1.09
8	0-7.5	100	41.4	50.6	8.0	33.7	11.3	4.8	1.10	7.22	3.84
	7.5-15	100	36.9	53.4	9.7	33.3	4.9	1.3	.36	4.11	2.29
	15-30	100	39.8	50.0	10.2	28.4	4.4	.82	.32	3.73	2.19
9	0-7.5	75	79.6	15.0	5.4	20.9	5.9	2.7	.46	4.97	1.59
	7.5-15	74	80.6	14.0	5.4	26.2	5.3	1.7	.32	4.22	1.67
	15-30	80	84.4	9.8	5.8	16.1	3.8	.65	.31	3.57	1.64
10	0-7.5	79	74.0	18.4	7.6	34.0	8.6	3.3	.55	5.72	2.42
	7.5-15	78	76.1	16.4	7.5	29.6	4.3	1.2	.32	3.58	1.39
	15-30	81	81.2	11.0	7.8	19.7	3.8	.45	.28	3.46	1.09
11	0-7.5	87	44.0	41.0	15.0	74.7	11.6	6.6	.81	4.04	8.72
	7.5-15	100	41.5	43.4	15.1	67.8	9.0	4.0	.39	3.74	7.45
	15-30	93	43.4	40.8	15.8	48.0	8.9	2.0	.37	2.01	7.11
12	0-7.5	82	52.6	39.8	7.7	40.5	8.4	3.9	.52	3.74	6.63
	7.5-15	79	59.3	28.0	12.7	50.3	8.2	2.3	.44	2.41	6.15
	15-30	84	51.4	36.8	11.8	40.6	7.5	1.5	.42	1.86	6.13
13	0-7.5	93	48.0	38.6	13.4	56.4	19.7	8.0	1.05	11.55	6.45
	7.5-15	87	44.1	41.3	14.6	43.5	6.5	1.7	.52	5.15	2.44
	15-30	86	45.2	40.0	14.8	42.0	5.7	.95	.42	4.73	2.28
14	0-7.5	74	66.1	25.7	8.2	48.0	12.7	6.4	.71	6.09	6.04
	7.5-15	75	68.8	23.0	8.2	33.0	6.2	1.8	.46	3.73	2.66
	15-30	70	66.2	25.0	8.8	26.8	5.1	.95	.46	3.22	2.37
15	0-7.5	78	78.4	15.9	5.7	24.1	5.6	2.9	.31	4.80	1.84
	7.5-15	6	81.3	12.9	5.8	21.4	5.1	1.3	.24	3.55	1.39
	15-30	63	78.2	13.6	8.2	18.6	4.3	.43	.27	3.18	1.09
16	0-7.5	70	76.8	18.2	5.0	25.0	6.7	2.9	.40	4.72	2.28
	7.5-15	73	77.8	16.2	6.0	26.8	4.3	1.0	.30	3.11	1.00
	15-30	70	79.8	13.0	7.2	25.7	4.1	.44	.34	4.14	1.00
17	0-7.5	98	74.8	20.4	4.8	24.0	7.1	2.5	.56	8.36	2.22
	7.5-15	97	70.3	24.8	4.9	18.1	4.4	1.5	.37	3.04	1.48
	15-30	98	71.8	23.0	5.2	11.8	3.6	.64	.39	2.42	1.28
18	0-7.5	83	80.3	13.3	6.4	23.1	5.6	2.6	.32	3.96	2.49
	7.5-15	85	80.2	13.4	6.4	19.8	5.2	1.4	.24	2.88	2.18
	15-30	93	81.8	12.0	6.2	17.3	4.5	.43	.27	3.27	1.55
19	0-7.5	64	75.4	17.9	6.7	30.0	5.9	2.7	.27	3.89	1.99
	7.5-15	69	74.4	15.4	9.2	34.0	4.5	.66	.31	3.52	1.12
	15-30	69	79.8	12.0	8.2	22.9	3.8	.33	.34	3.88	1.09
20	0-7.5	57	68.9	23.0	8.1	36.3	6.9	3.6	.42	6.13	3.33
	7.5-15	67	71.9	19.5	8.6	31.8	4.4	.9	.26	3.34	2.17
	15-30	63	80.8	12.0	7.2	21.9	3.7	.31	.23	3.62	1.00
21	0-7.5	100	46.3	45.2	8.5	42.4	9.7	4.2	.90	6.19	3.03
	7.5-15	100	42.8	48.7	8.5	35.8	6.6	2.0	.42	5.37	2.28
	15-30	100	45.8	46.0	8.2	22.9	4.8	.99	.38	4.11	1.73
22	0-7.5	82	80.9	13.7	5.4	21.4	5.9	2.5	.34	3.84	1.67
	7.5-15	82	80.4	13.2	6.4	20.3	4.7	.78	.22	3.17	.79
	15-30	85	81.8	11.0	7.2	18.2	4.2	.31	.18	3.07	.72
23	0.7-5	87	71.9	18.7	9.4	29.8	6.2	2.1	.24	3.70	1.57
	7.5-15	74	62.9	23.7	13.4	34.3	5.9	1.3	.15	3.49	1.43
	15-30	83	72.8	18.0	9.2	23.2	4.8	1.1	.16	2.71	1.19

Table 6.--*Physical properties of soil on eight selected test sites near [illegible]*

Site	Depth	Total pore space by volume	Capillary pore space by volume	Noncapillary pore space by volume	Bulk [illegible]	[illegible]
	[illegible]	*Percent*				
1	0-7.5	41.4	22.3	19.1	1.34	28
	7.5-15	53.2	29.7	23.5	1.07	28
	15-30	45.2	21.1	24.1	1.17	.13
4	0-7.5	42.9	26.9	16.0	1.34	.34
	7.5-15	33.3	7.8	25.5	1.52	.28
	15-30	35.1	17.5	[illegible]	1.50	[illegible]
8	0-7.5	58.8	49.9	[illegible]	[illegible]	[illegible]
	7.5-15	53.4	46.5	[illegible]	[illegible]	17
	15-30	47.5	41.8	[illegible]	1.21	[illegible]
9	0-7.5	48.8	22.3	26.4	1.28	.50
	7.5-15	45.4	18.6	26.8	1.19	[illegible]
	15-30	37.9	16.9	21.0	1.35	.17
12	0-7.5	53.4	38.5	14.9	1.29	76
	7.5-15	61.2	42.8	18.4	[illegible]	[illegible]
	15-30	44.0	34.9	9.1	1.22	.17
13	0-7.5	68.4	55.5	12.9	.77	[illegible]
	7.5-15	67.1	50.1	17.0	.72	.20
	15-30	52.8	37.7	15.1	1.11	.36
16	0-7.5	38.5	15.7	22.8	1.31	[illegible]
	7.5-15	40.6	19.4	21.2	1.37	.30
	15-30	41.7	12.9	28.8	1.35	[illegible]
23	0-7.5	23.6	21.5	2.1	1.46	[illegible]
	7.5-15	38.1	26.1	12.0	[illegible]	[illegible]
	15-30	32.5	26.2	6.3	1.59	[illegible]

APPENDIX III

Survival Function

$$S = .90106\ YP \left\{ \frac{e^{-\left|\frac{\frac{F}{100} - 1}{1 - I}\right|^{n}} - e^{-\left(\frac{1}{1 - I}\right)^{n}}}{1 - e^{-\left(\frac{1}{1 - I}\right)^{n}}} \right\}$$

Where:

$$YP = A + B$$

$$A = (5959.3 - 16.711\ K)(0.2 - N)^{1.6}$$

$$B = \left\{ (6.0053 \times 10^{18})\ e^{-\left|\frac{\frac{(300 - K)}{220} - 1}{0.48}\right|^{10}} \right\} (0.2 - N)^{20}$$

$$n = 3 + 2.2\ e^{-\left|\frac{\frac{(K - 90)}{210} - 1}{0.325}\right|^{6}}$$

$$I = 0.4975 + 0.0425\ e^{-\left|\frac{\frac{(300 - K)}{210} - 1}{0.62}\right|^{4.7}}$$

Limits:

$90 \leq K \leq 300$
$0.04 \leq N \leq 0.18$
$0 \leq F \leq 70$

$R^2 = 0.93$
$s_{y \cdot x} = 3.6$
$\bar{y} = 8.7$

STERMITZ, JAMES E., MURRAY G. KLAGES, and JAMES E. LOTAN
1974. Soil characteristics influencing lodgepole pine regeneration near West Yellowstone, Montana. USDA For. Serv. Res. Pap. INT-163, 16 p., illus. (Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.)

In direct seeding from soils of volcanic origin, seedbed preparation treatments affected germination and first-year survival insignificantly, compared to site differences. A strong positive relation between survival and the amount of silt plus clay in the soil was identified. Available potassium and total nitrogen had a negative influence, attributable to poor seed-soil contact and competition for moisture on more fertile sites. The three soil properties explained 93 percent of the variance in seedling survival. A response surface for the three soil properties was developed, as an aid in predicting survival.

OXFORD: 23; 181.525.
KEYWORDS: regeneration, lodgepole pine, seedling establishment, soil characteristics, direct seeding.

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Montana State University)

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University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham

Reno, Nevada (in cooperation with the University of Nevada)

Prediction of Height Increment for Models of Forest Growth

Albert R. Stage

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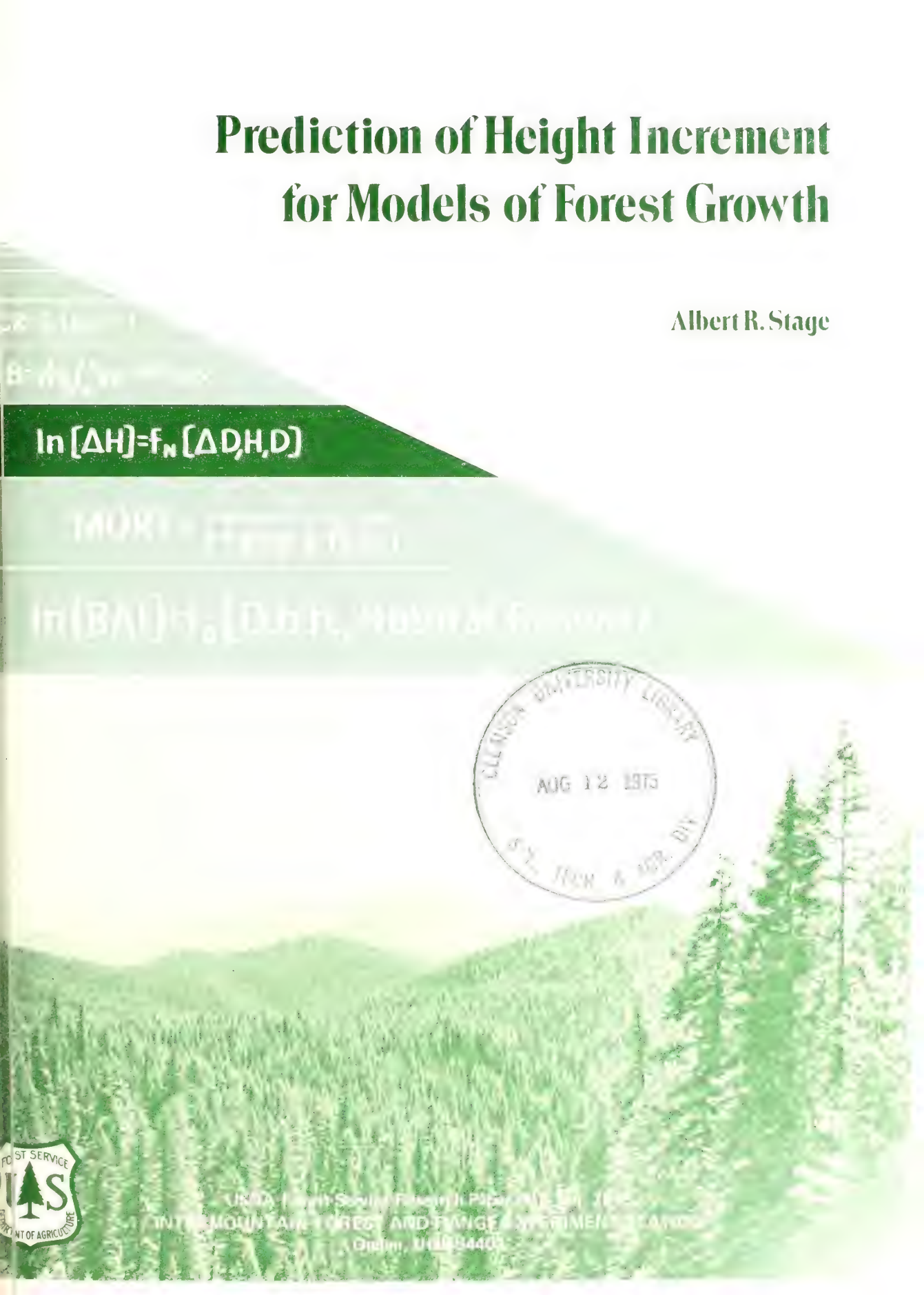

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Prediction of Height Increment for Models of Forest Growth

Albert R. Stage

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401
Roger R. Bay, Director

THE AUTHOR

ALBERT R. STAGE is principal mensurationist at the Forestry Sciences Laboratory, Moscow, Idaho. His research has included studies of planning methods for forest management, forest inventory techniques, site evaluation, and methods for estimation of stand growth and yield. He is Project Leader of a research team studying the problems of intensive culture of the cedar-hemlock-grand fir ecosystem and problems of timber management planning.

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ABSTRACT

Functional forms of equations were derived for predicting 10-year periodic height increment of forest trees from height, diameter, diameter increment, and habitat type. Crown ratio was considered as an additional variable for prediction, but its contribution was negligible. Coefficients of the function were estimated for 10 species of trees growing in 10 habitat types of northern Idaho and northwestern Montana. A procedure using these coefficients for calculating the components of current annual volume increment from diameter, height, and past radial increment is described, and its FORTRAN implementation listed.

INTRODUCTION

How fast do trees grow in height? The answer requires a great deal of detail about he tree's environment and about the tree itself, or some specific growth measure on the ree that indicates the combined effects of all environmental factors and the tree's ndividual characteristics. Diameter increment is such a measure. It is much more asily measured than height increment, and responds to the same growth determinants.

Diameter increment, however, is much more responsive to effects of stand stocking han is height increment. Past effects of stocking on height growth relative to diam- ter growth are indicated by the tree's form, as measured by the height/d.b.h. ratio, nd by its crown ratio (live crown length/total height). In this report, we seek to evelop a prediction equation that relates height increment to concurrent diameter ncrement, tree height, diameter, crown ratio, and habitat type (Daubenmire and aubenmire 1968).

To use this equation for calculating the height increment component of current olume increment of trees on inventory plots, a computer subroutine is provided in he appendix. For more extended prognoses, the same equation for predicting height ncrement can be imbedded in a computer model of forest stand development (Stage 1973).

For many years Forest Survey in the Intermountain Forest and Range Experiment tation has calculated current volume increment from changes in height computed from iameter increment and diameter. Wright (1961) recommended a similar procedure. Both pproaches were derived from a single curve of total height over d.b.h. by determining he differences in the curve height for current d.b.h. and for d.b.h. plus diameter ıcrement. Hence, these approaches assume that all trees of a particular species fol- ow height/diameter curves that have the same slope for a given d.b.h.

Better prediction equations should be possible where data are available from irect measurements of height increment. Prediction equations presented in this report re based on analysis of 1,165 trees felled as part of management planning inventories f the Kaniksu, Coeur d'Alene, St. Joe, and Lewis and Clark National Forests in northern daho and western Montana.

DESCRIPTION OF DATA

Ten species distributed among 10 habitat types are represented in the data (table 1). Distribution of samples with respect to height and d.b.h. are shown by species in figure 1, and by habitat types in figure 2. Periodic diameter growth (inside bark), ΔD, was measured concurrently with periodic height growth, ΔH, for the most recent 10-year period. Values for height (H) and diameter at breast height (D)[1/] were determined as they existed at the start of the increment period because the regression estimate is required to predict the change in height as a function of height, diameter, and projected diameter increment (inside bark). Of necessity, the crown ratio used was observed at the end of the growth period. Fortunately, crown ratio changes very slowly within 10 years.

The trees were measured during the inventories of 1969-1972. Consequently, their most recent 10-year growth is influenced by the climate and other temporal events from about 1959 to 1972.

[1/] Bark increment was not deducted when past d.b.h. was calculated. The slight overestimate of past d.b.h. can cause only a slight bias in the estiamte of height growth.

Table 1.--*Distribution of sample trees by species and habitat type*

Species	Habitat										Total
	Pseudotsuga/ Symphoricarpos	*Pseudotsuga/ Physocarpus*	*Pseudotsuga/ Calamagrostis*	*Abies grandis/ Xerotrium*	*Thuja/ Xerotrium*	*Tsuga heterophylla/ Xerotrium*	*Abies lasiocarpa/ Xerotrium*	*Abies lasiocarpa/ Calamagrostis*	*Abies lasiocarpa/ Carex geyeri*	*Abies lasiocarpa/ Vaccinium scoparium*	
Ponderosa pine		12		16	8						36
Douglas-fir	108	53	28	132	13	40	16	6		6	402
Western larch		7		17	9	27	4	14		2	80
Lodgepole pine		6	49	14	3	17	1	8		88	186
Grand fir				49	3	76	1				129
Western white pine				22	2	76		1		1	102
Western redcedar				1	7	39					47
Western hemlock					1	104	8				113
Engelmann spruce			2			3		6	3		14
Subalpine fir						5	13	32	5	1	56
Total	108	78	79	251	46	387	43	67	8	98	1,165

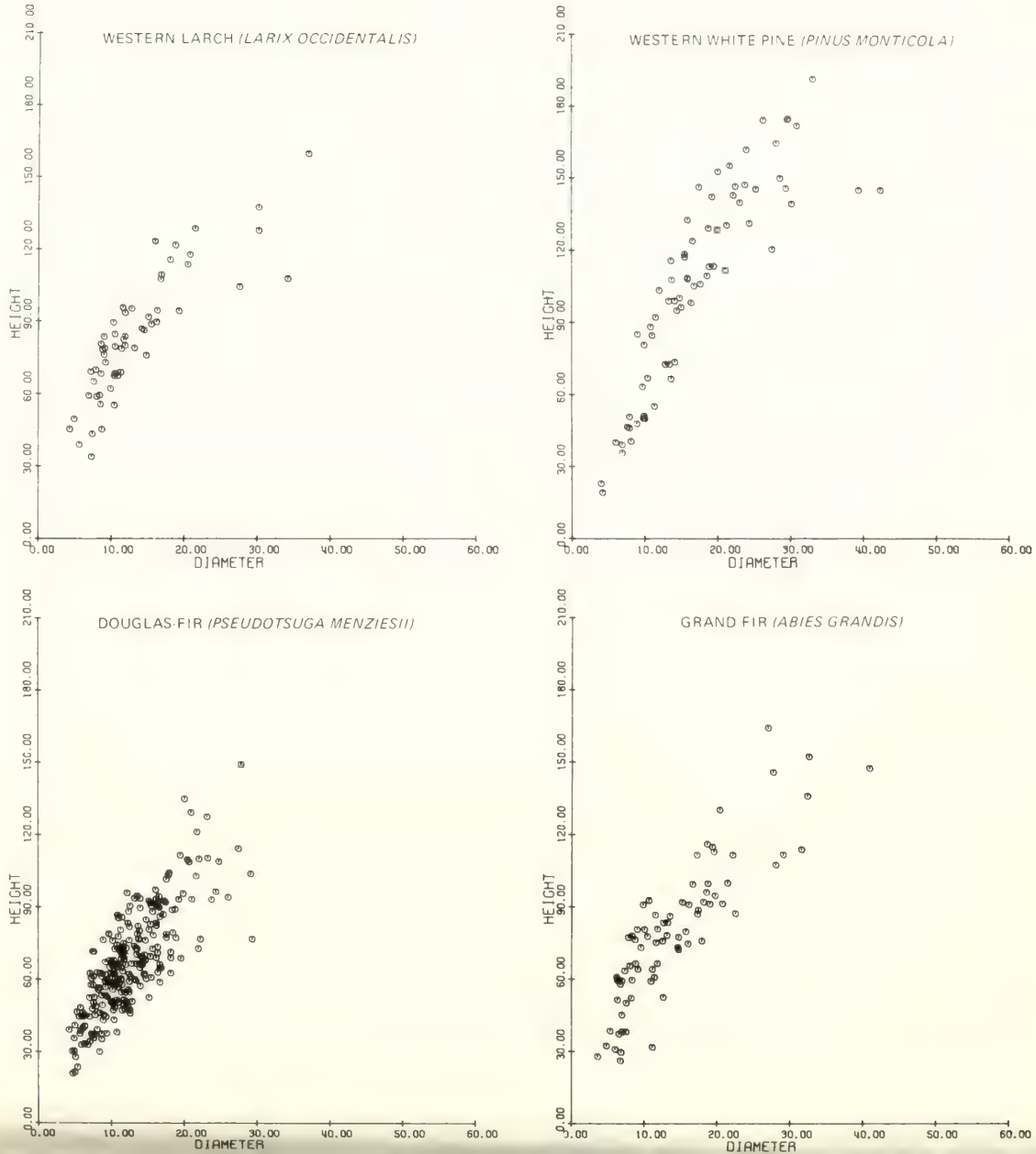


Figure 1. Distribution of sample trees by species, height, and diameter.

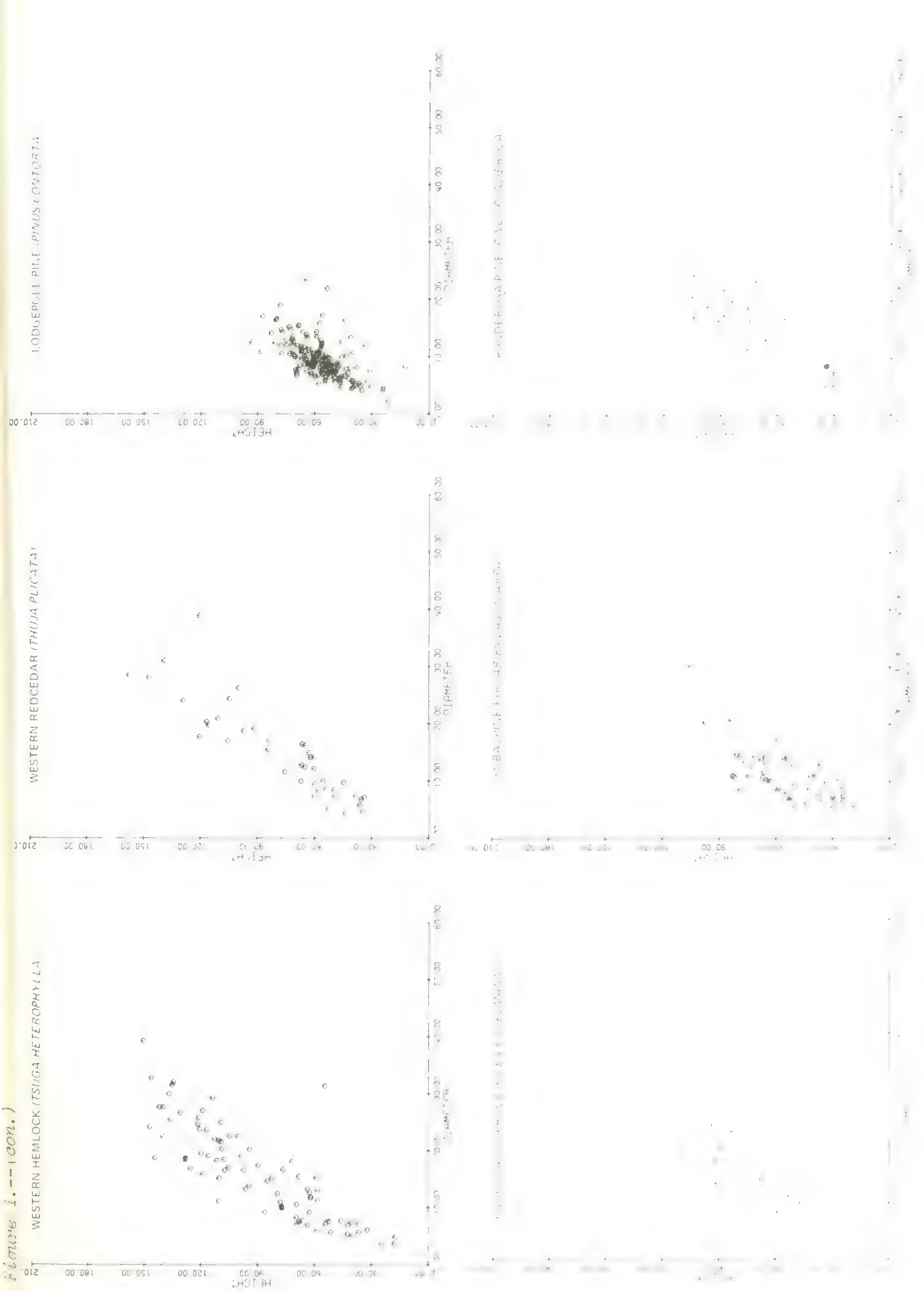
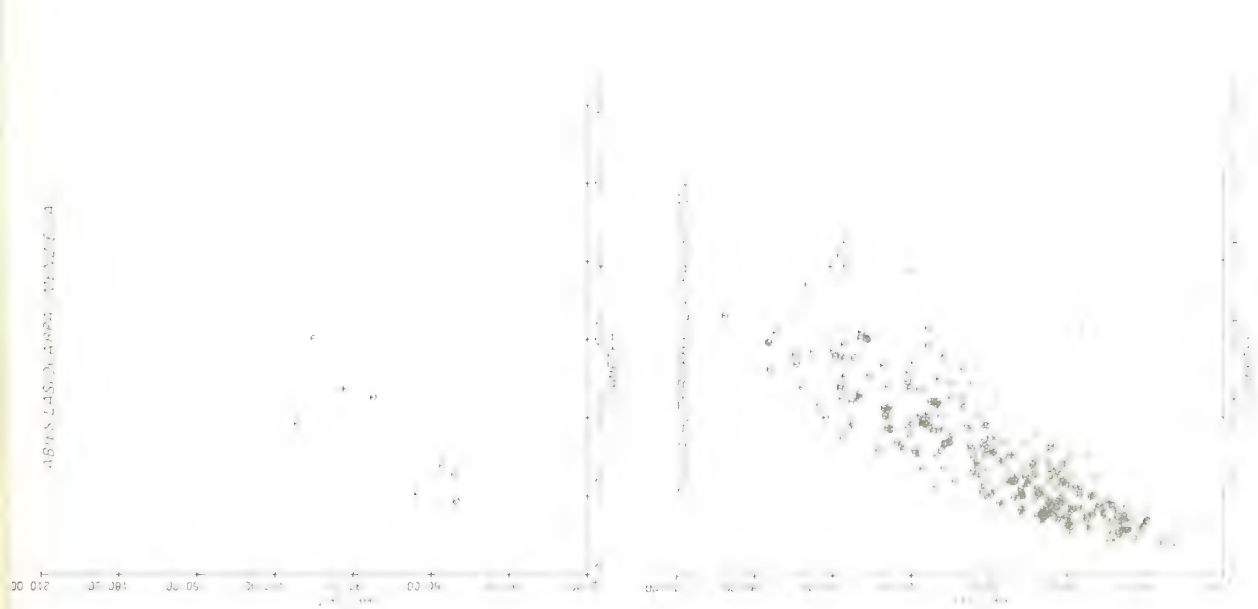
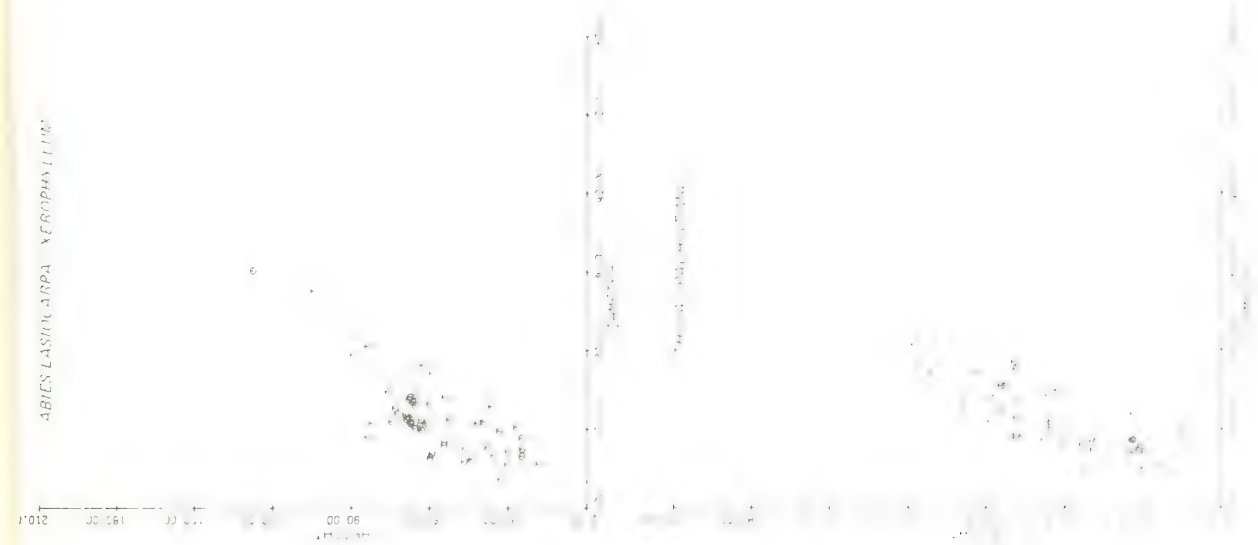
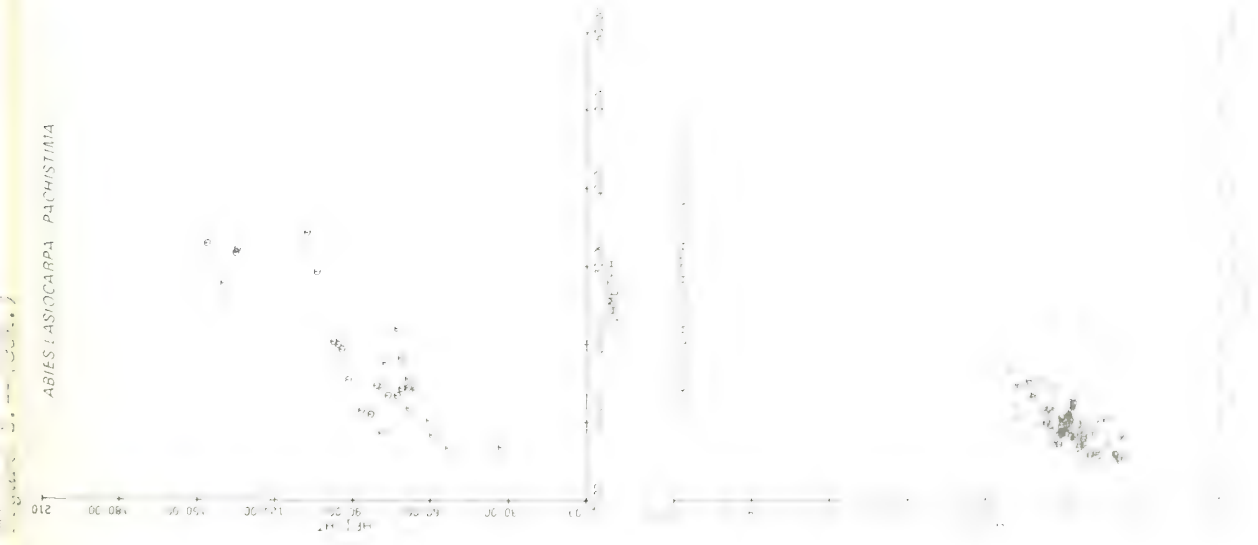

LODGEPOLE PINE (PINUS CONTORTA
WESTERN REDCEDAR (THUJA PLICATA)
WESTERN HEMLOCK (TSUGA HETEROPHYLLA

Figure 1.--(con.)

PSEUDOTSUGA SYMPHORICARPOS
ABIES GRANDIS PACHISTIMA
PSEUDOTSUGA PHYSOCARPUS
PSEUDOTSUGA / CALAMAGROSTIS
HEIGHT
DIAMETER
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
10.00
20.00
30.00
40.00
50.00
60.00




ABIES LASIOCARPA VENUSTA


ABIES LASIOCARPA PACHISTIMA

DERIVING THE FUNCTIONAL FORM FOR THE PREDICTION EQUATIONS

A set of height/diameter curves for three even-aged stands of grand fir is shown in figure 3. These curves are plotted solutions of a nonlinear equation for predicting tree height from diameter, site quality, and age of the stand. Analysis of these data confirmed that the allometric relation:

$$\ln(H) = a + b \ln(D) \qquad (1)$$

does indeed apply to the development of trees as age increases, but that the coefficients a and b depend upon the competitive status of the trees. Competitive status can be defined by the distance of the (H,D) point for a particular tree from the curve of relation (1) for dominant trees (Perkal and Battek 1955). The dashed line shows the trend followed by the average for the dominant and codominant trees in the stand. Trees in lower crown classes move more steeply upward. Conversely, dominants move along lines of lower slope.

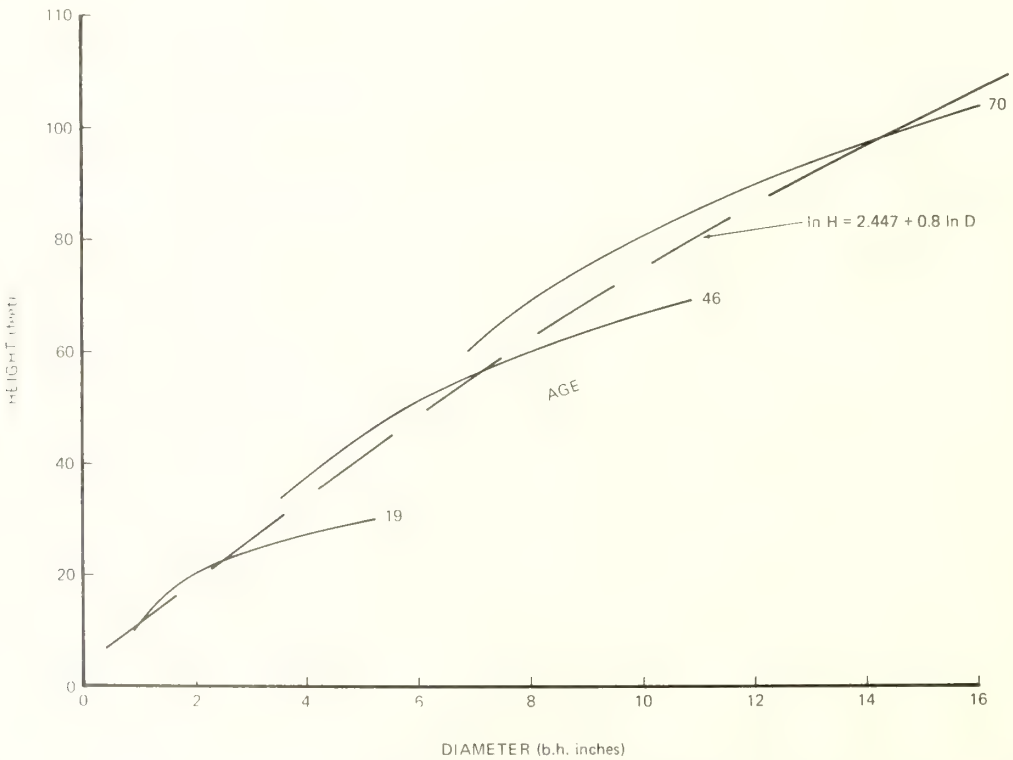


Figure 3. Sequence of height/diameter curves for even-aged stands of grand fir.

Instantaneous growth rates can be obtained by taking the differential of equation (1):

$$\Delta H = b \frac{H}{D} \Delta D \qquad (2)$$

or, in its logarithmic form:

$$\ln(\Delta H) = \ln(\Delta D) + \ln(H) - \ln(D) + \ln(b) \qquad (3)$$

On the other hand, periodic growth rates expressed as a finite difference derived from (1) would be:

$$\ln(H_2) - \ln(H_1) = b(\ln(D_2) - \ln(D_1))$$

which is the same as:

$$\ln(H_2/H_1) = b \ln(D_2/D_1) \qquad (4)$$

where the subscripts 1 and 2 designate measured values at the start and end of growth period, respectively.

Models were derived from (2), (3), and (4) by using various transformations of height, the ratio of height to diameter, and crown ratio to estimate the b parameter for each species. The best transformations of these independent variables were selected by combining them in groups of sets for screening overall combinations of the groups by using one set from each group (Grosenbaugh 1967). Coefficients in these alternative models were estimated by least-squares regression. Goodness-of-fit indices (Furnival 1961) for the several transformations of the dependent variable were compared using the best regression for each transformation of the dependent variable.

For the screening of these alternative models, data from 909 trees of 10 species in the northern Idaho forests were used.

Differential Model

The dependent variable in this model is the 10-year periodic height increment, ΔH. Some coefficients (c_j) in the model may be different for each species; other coefficients may be constant for all 10 species. Those that vary with species have an additional subscript i.

$$\Delta H = \frac{H}{D} \Delta D [c_{1_i} + c_{2_i} \ln(CR) + c_{3_i} \frac{\Delta D}{D} + c_{4_i} (\frac{\Delta D}{D})^2 + c_{5_i} \ln(H) + c_{6_i} \ldots]$$

The expression in the brackets represents the estimate of b in equation (2). In computation, c_{6_i} was the set of constant terms in the regression model.

Table 2 is an analysis of variance showing the improvement in the regression sum-of-squares for successively more complex collections of variables. In this table, for example, comparison level 2 indicates that when either the coefficients of $H\Delta D/D$ or the constant terms are allowed to vary by species, then the fit is improved by a significant amount. Of these two alternatives, the former has a slight advantage. At comparison level 3, varying constant terms by species is of little value so long as the coefficients of $H\Delta D/D$ depend on species. However, the variable $\ln(H)$ is shown to be needed to represent the effect of changing height on the b coefficient. At comparison level 4, crown ratio is still of little use, but addition of $\Delta D/D$ and its square results in a considerable improvement.

Table 2.--*Analysis of improvement of regression model attributable to adding variables. Dependent variable = ΔH*

Comparison level	Source	d.f.	Proportion of remaining variance explained[1/]	Marginal sum of squares[1/]	Mean square	F
1	[1	1		49469.808		
	$H\Delta D/D$]	1		2263.450	2263.450	263.0
2	[$H\Delta D/D_{isp}$	9	0.065	776.592	86.288	10.0
	1_{isp}	9	.060	728.725	80.969	9.4
3	1_{isp}	9	.0168	260.549	28.950	3.4
	[ln (H)]	1	.151	1491.782	1491.782	173.3
4	ln (CR)	10	.048	479.677	47.967	5.6
	1_{isp}	9	.0158	219.627	23.403	2.7
	[$\Delta D/D, (\Delta D/D)^2$]	2	.108	905.914	452.957	52.6
	Error	878		7556.068	8.606	

[1/] Increase in explanatory power for regression due to adding variables to the model composed of those variables bracketed in the levels above.

Finite Difference Model

The dependent variable in this model is $\ln(H_2/H_1)$. When an expression for b analogous to its form in the differential model is inserted in the finite difference model (4), we obtain:

$$\ln(H_2/H_1) = \ln(D_2/D_1)\ [c_{1_i} + c_{2_i} \ln(CR) + c_3 \ln(D_2/D_1) + c_4 (\ln(D_2/D_1))^2$$

$$+ c_{5_i} \ln(H) + c_{6_i} /\ln(D_2/D_1)]$$

To compare the utility of the two alternative forms of the dependent variable, we use the maximum likelihood index of fit (Furnival 1961). The basis for the comparison is the standard error of estimate of the untransformed dependent variable. Standard errors of estimate for other transformations of the dependent variable are converted for comparison by multiplying them by the inverse of the geometric mean of the derivative of the transformation. The derivative of $\ln(H_2/H_1)$ with respect to ΔH is:

$$f'(\Delta H) = \frac{\partial \ln(H_2/H_1)}{\partial \Delta H} = \frac{\partial \ln(1. + \Delta H/H_1)}{\partial \Delta H}$$

$$= \frac{H_1}{H_2} \cdot \frac{1}{H_1} = \frac{1}{H_2}$$

Accordingly, the inverse of the geometric mean is given by:

$$\frac{1}{[\prod (\Delta H)]} = \exp[\Sigma \ln(\quad)/n]$$

The index-of-fit is 3.54 for the best collection of variables (through level 4) in the finite difference model. This index is compared to the standard error of estimate of the differential model, which is ±2.93 feet. Hence, the differential model is superior.

Table 3 is an analysis of variance for the finite difference model with comparisons similar to those in table 2. The variables in this model that are analogous to those in the differential model are effective as predictors to about the same degree.

Table 3.--*Analysis of improvement of regression model attributable to adding variables. Dependent variable* = $\ln(H_2/H_1)$

Comparison level	Source	d.f.	Proportion of remaining variance explained[1/]	Marginal sum of squares[1/]	Mean square	F
1	[1	1				
	ln (D_2/D_1)]	1		3.1589	3.1589	1707.5
2	[$\ln(D_2/D_1)_{isp}$]	9	0.091	.3372	.0375	20.3
	1_{isp}	9	.031	.1365	.0152	8.2
3	1_{isp}	9	.015	.0754	.00838	4.5
	[$\ln(H)$]	1	.252	.7702	.7702	416.3
4	[$\Delta D/D, (\Delta D/D)^2$]	2	.258	.5921	.2961	160.0
5	1_{isp}	9	.018	.04633	.00515	2.8
	Error	886			.00185	

[1/] Increase in explanatory power for regression due to adding variables to the model composed of those variables bracketed in the levels above.

Differential Model-- Logarithmic Form

When the differences between the observed and predicted values of ΔH are plotted over the predicted values, the variance of the difference increases with larger values of the prediction. As a consequence, faster growing trees are given undue weight in estimating values of the coefficients. The logarithmic form of the model (3) should decrease the variance of the residuals associated with large predictions. The preceding analyses showed that the allometric coefficient (b) varied with species and the

relation of height, diameter, and diameter increment. These effects could be incorporated quite readily by multiplying each independent variable by a coefficient to be estimated, and by introducing a constant term for each species. In the logarithmic form, the possibility of zero values for ΔD must be considered. Measurements of diameter growth are usually recorded only to the nearest 1/20 inch. By shifting the entire scale up 1/20 inch, zero values can be accommodated without distorting the overall relation.

Thus, the logarithmic form of the differential model is:

$$\ln(\Delta H) = c_{1_i} + c_2 \ln(\Delta D + .05) + c_3 \ln(D) + c_4 \ln(H) \qquad (5)$$

For the 909 trees from the northern Idaho forests, the following coefficients for this model gave a better index of fit (±2.73 feet) than the differential model with the loss of fewer degrees of freedom:

c_{1_i} =	3.4448	Western white pine
	3.1258	Western larch
	3.1424	Douglas-fir
	3.2939	Grand fir
	3.1508	Western hemlock
	2.9357	Western redcedar
	3.0706	Lodgepole pine
	3.2221	Engelmann spruce
	2.8355	Subalpine fir
	3.4380	Ponderosa pine
c_2 =	+0.37401	$\ln(\Delta D + 0.05)$
c_3 =	-0.29805	$\ln(D)$
c_4 =	-0.13170	$\ln(H)$
s^2 =	0.1775	

When the same model was applied to the 265 lodgepole pine and Douglas-fir trees from the Lewis and Clark National Forest, the values of the coefficients were quite different from those above. The estimated residual variance for these data was $s^2 = 0.1630$. The difference between these two populations is apparent in the following averages:

	Northern Idaho Forests	*Lewis and Clark N.F.*
ΔH	6.5	1.4
ΔD	1.8	0.44

Differences in growth rates correspond to marked differences in habitat for those species that are common to the two geographic sources of data. As a consequence of the differing habitats, the Lewis and Clark trees would show a much lower average site index than the northern Idaho trees. Furthermore, the Lewis and Clark trees are generally older. To accommodate these differences, data from the two sources were merged and the differential model modified to permit coefficients to vary with habitat as well as species. If all four coefficients were unique with respect to species and habitats, then there would be 204 coefficients to be estimated by a separate regression solution of equation (5) for each of the 51 entries in table 1. Instead, the four coefficients in the logarithmic form of the differential model were varied according to species and

habitat in repeated regression problems (table 4). The final line represents the best model of the series. Coefficients derived from this solution are given in table 5. The ratio of the mean-square deviation from regression to the mean-square deviation about the mean is 0.2722 for this model. That is, the model accounts for about 73 percent of the variance of logarithm of height increment among the 1,165 trees in the sample. Converting the residual error to the scale of feet of height increment (Furnival's index), the mean-square error of estimate would be ±1.97 feet.

To illustrate the implications of this functional form for height increment in the context of stand development, the successive height/diameter curves were plotted for a typical even-aged stand of grand fir carried through four decades of simulated growth (fig. 4). The curves in figure 4 show that the prediction functions for height increment derived in this report can generate successive curves that conform to the general shape and level of typical height/diameter curves in even-aged stands shown in figure 3. Conformation of these curves for simulated stand development also depends on the way diameter increment and mortality change among diameter classes within the stand.

Table 4.--*Effect of varying coefficients by species and habitat on the mean square residual of the logarithmic form of the differential model*

Number of coefficients in model	Variable				Mean square residual
	1	ln(*D*+.05)	ln (*D*)	ln (*H*)	
22	H	*	*	H	0.[illegible]
31	S	*	H	H	.[illegible]
32	S+H	*	*	H	.2008
32	S+H	H	*	*	.[illegible]
40	S	H	H	H	.1875
41	S+H	H	H	*	.[illegible]

Key: * indicates a single coefficient for all species and habitats.
H indicates a unique coefficient of the indicated variable for each habitat.
S indicates a unique coefficient of the indicated variable for each species.

Table 5.--*Coefficients for estimating the logarithm of 10-year periodic height growth*

	Habitat									
	Pseudotsuga/ Symphoricarpos	*Pseudotsuga/ Physocarpus*	*Pseudotsuga/ Calamagrostis*	*Abies grandis/ Pachistima*	*Thuja/ Pachistima*	*Tsuga heterophylla/ Pachistima*	*Abies lasiocarpa/ Pachistima*	*Abies lasiocarpa/ Xerophyllum*	*Abies lasiocarpa/ Menziesia*	*Abies lasiocarpa/*
	Intercept coefficient									
Ponderosa pine		3.0970		3.8908	3.4091					
Douglas-fir	2.4253	2.7460	2.9966	3.5398	3.0581	3.3143	3.9207	2.4395		2.80
Western larch		2.7512		3.5450	3.0633	3.3195	3.9259	2.4447		2.81
Lodgepole pine		2.7973	3.0480	3.5911	3.1094	3.3656	3.9720	2.4908		2.85
Grand fir				3.6535	3.1718	3.4280	4.0344			
Western white pine				3.8157	3.3340	3.5902		2.7154		3.08
Western redcedar				3.3143	2.8326	3.0888				
Western hemlock					3.0256	3.2818	3.8881			
Engelmann spruce			2.9080			3.2257		2.3509	1.6339	
Subalpine fir						3.1336	3.7400	2.2588	1.5419	2.62
	Variable coefficients									
Variable										
$\ln(\Delta D+0.05)$	.96586	.11127	.61883	.44920	.27100	.40908	.61661	.05592	.48219	.754
$\ln(D)$	-.31462	.00278	-.56538	-.35626	-.23160	-.22856	-.47228	.04938	.21472	-.370
$\ln(H)$	-.1955	-.1955	-.1955	-.1955	-.1955	-.1955	-.1955	-.1955	-.1955	-.195

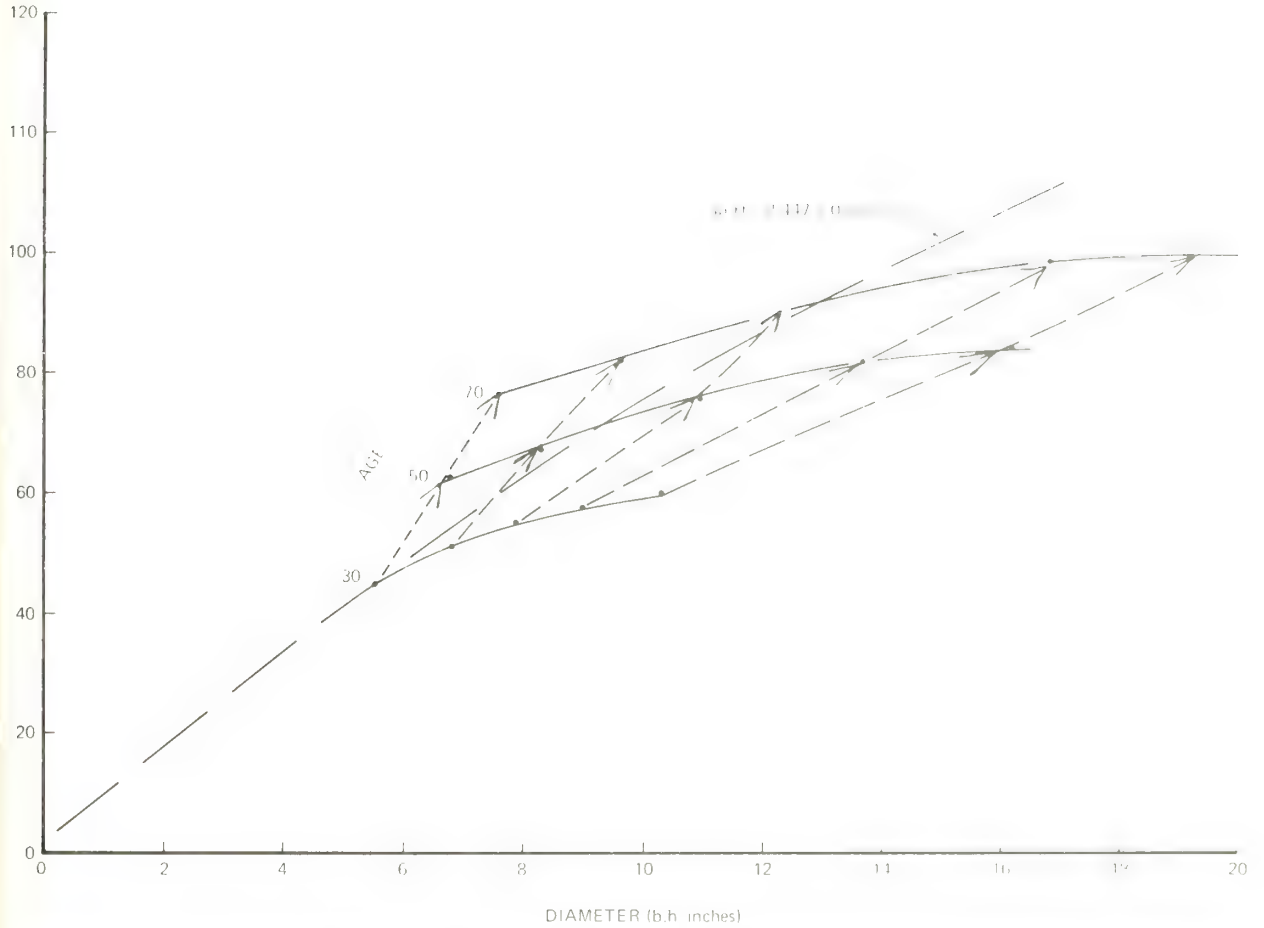


Figure 4.--Projected height/diameter curves for [illegible] habitat.

Removing Bias in Logarithmic Form

When the variable to be predicted is analyzed by making a logarithmic transformation, a bias is introduced when the inverse transformation is used to convert the estimate to the original natural scale. Effect of the bias would be cumulative when these prediction equations are used repetitively to simulate growth of trees and stands through successive periods of time. By removing the bias, repetitive application will produce the same height from the accumulated predictions of increment as would be the result of cumulating observed values of the log-normally distributed height increment.

Size of the bias depends on the residual variance, which is listed as 0.1853 on the last line of table 4, for the logarithmic model.

Bradu and Mundlak (1970) devised a correction for the bias that recognizes the effect of sampling error on the parameters of the regression. Unfortunately, their method requires the values of the inverse covariance matrix which is a 41 X 41 array. As an alternative, a simple correction that is conditional on the sample values of the parameters seems adequate. To determine the corrected estimate of the mean on the original scale, the value of one-half the residual variance is added to the estimate on the logarithmic scale before making the transformation back to the natural scale. In this case, the amount to be added is 0.1853 ÷ 2 = 0.09265. The effect is to multiply the uncorrected estimate of height increment by 1.0971.

APPLICATIONS

Calculating Current Annual Increment

Current annual volume increment is commonly calculated by measuring or estimating the two major dimensions of volume increment: change in tree d.b.h. (inches) and change in tree height (feet). Then, these changes are added to present d.b.h. and total height, and the volume change is determined from the difference between the volumes obtained from a volume table or volume equation that relates tree volume to d.b.h. and total height. The prediction equations developed in this report can be used to calculate the 10-year periodic height increment from the corresponding 10-year periodic diameter increment, initial d.b.h., and initial height. When past periodic diameter increment is used to determine future diameter increment, a problem arises because diameter growth generally declines with age. Consequently, the current annual rate would differ from the periodic rate divided by period length. To remedy this problem, we can invoke the observation that whereas diameter increment declines with age, basal area increment usually remains constant (Spurr 1952, p. 214; Smith 1962, p. 55).

The sequence of calculations is:

1. Determine past increase in diameter squared. If increment was measured outside bark, convert to increment inside bark. If measured for a period of y years, convert to a 10-year basis.

$$DDS = (d_i^2 - d_{i-y}^2) * 10/y$$

2. Use past DDS to estimate future ΔD (10-year periodic increment):

$$\Delta D = \sqrt{d_i^2 + DDS} - d_i \quad \text{(inches)}$$

3. Solve equation (5) using the set of coefficients from the column of table 5 or the applicable habitat type, and using the first coefficient for the appropriate pecies:

$$\ln(\Delta H) = a_1 + a_2 \ln(\Delta D + 0.05) + a_3 \ln(D_i) + a_4 \ln(H_i)$$

$$\Delta H = \exp(\ln(\Delta H) + 0.09265) \quad \text{(feet)}$$

4. Convert growth estimates to diameter and height 1 year hence:

$$D_{i+1} = \sqrt{D_i^2 + BKR * DDH/10}$$

$$H_{i+1} = H_i + \Delta H/10$$

here $BKR = (D_i/d_i)^2$ is the square of the ratio of d.b.h. to diameter inside bark at reast height.

A computer subroutine prepared in FORTRAN IV to carry out this sequence of calculations is given in the appendix.

If growth for an arbitrary interval (y) greater than 1 year is desired, then the ivision by 10 in the last two equations would be replaced by multiplication by the alue of $y/10$. That is,

$$D_{i+y} = \sqrt{D_i^2 + BKR * DDH * y/10}$$

$$H_{i+y} = H_i + \Delta H * y/10$$

LITERATURE CITED

Bradu, D., and Y. Mundlak
1970. Estimation in log-normal linear models. J. Am. Stat. Assoc. 65:198-211.

Daubenmire, R., and J. Daubenmire
1968. Forest vegetation of eastern Washington and northern Idaho. Wash. Agric. Exp. Stn. Tech. Bull. 60, 104 p., illus.

Furnival, George M.
1961. An index for comparing equations used in constructing volume tables. For. Sci. 7(4):337-341.

Grosenbaugh, L. R.
1967. REX--Fortran-4 system for combinatorial screening or conventional analysis of multivariate regressions. U.S. For. Serv. Res. Pap. PSW-44, 47 p.

Perkal, J., and J. Battek
1955. (An attempt at estimating the development of stands.) (Polish) Sylwan 99(1) 12-31.

Smith, David M.
1962. The practice of silviculture. 578 p. John Wiley, New York.

Spurr, Stephen H.
1952. Forest inventory. 476 p. Ronald Press, New York.

Stage, Albert R.
1973. A model for the prognosis of forest stand development. USDA For. Serv. Res. Pap. INT-137, 32 p.

Wright, John P.
1961. Computation of height growth on continuous forest inventory plots. J. For. 59(10):772-773.

APPENDIX

FORTRAN IV Subroutine

```
      SUBROUTINE HTGT(ISP,IHAB,D,H,DD,D2,H2)
C        ISP IS SPECIES SUBSCRIPT
C        IHAB IS HABITAT SUBSCRIPT
C        D IS DIAMETER
C        H IS HEIGHT
C        DD IS 10-YEAR PAST DBH GROWTH
C        D2 IS THE NEW DIAMETER
C        H2 IS THE NEW HEIGHT
      DIMENSION ASPE(10),AHAB(10),BHAB(10),CHAB(10),BKR(10)
C
C      SPECIES SUBSCRIPT                    DEFINITION
C              1           WHITE PINE
C              2           WESTERN LARCH
C              3           DOUGLAS FIR
C              4           GRAND FIR
C              5           WESTERN HEMLOCK
C              6           CEDAR
C              7           LODGEPOLE
C              8           SPRUCE
C              9           SUBALPINE FIR
C              10          PONDEROSA PINE
      DATA ASPE/-0.260831,-0.531522,-0.536742,-0.423059,
     1  -0.569264,-0.762272,-0.485439,-0.625377,-0.717423,-0.185745/
C
C      HABITAT SUBSCRIPT                    DEFINITION
C              1           PSEUDOTSUGA / PHYSOCARPUS
C              2           PSEUDOTSUGA / SYMPHORICARPOS
C              3           PSEUDOTSUGA / CALMAGROSTIS
C              4           ABIES GRANDIS / PACHISTIMA
C              5           ABIES LASIOCARPA / PACHISTIMA
C              6           ABIES LASIOCARPA / XEROPHYLLUM
C              7           ABIES LASIOCARPA / MENZIESIA
C              8           ABIES LASIOCARPA / VACCINIUM
C              9           THUJA / PACHISTIMA
C              10          TSUGA HETEROPHYLLA / PACHISTIMA
      DATA AHAB/3.28270,2.96202,2.53339,4.07652,4.45741,
     1  2.97625,2.25931,3.34406,3.59483,3.85106/
      DATA BHAB/.11127472,.9658621,.61883491,.44919991,.61660659,
     1  .055921353,.48219198,.75457698,.27099925,.40907645/
      DATA CHAB/.0027789974,-0.31462085,-0.56538403,-0.35626483,
     1  -0.47227514,.049378771,.21472478,-0.37078756,-0.2315979,
     1  -0.22855937/
      DATA DSP/-0.19554013/
      DATA BKR /10* 1.09/
      D2 = SQRT(D**2 + DD * (2. * D - DD) * BKR(ISP) / 10.)
      H2 = H + EXP(ASPE(ISP) + AHAB(IHAB) + BHAB(IHAB) * ALOG(DD + 0.05)
     1  + CHAB(IHAB) * ALOG(D) + DSP * ALOG(H)) * 0.109698
      RETURN
      END
```

ALBERT R. STAGE

1975. Prediction of height increment for models of forest growth. USDA For. Serv. Res. Pap. INT-164, 20 p., illus. (Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.)

Functional forms of equations were derived for predicting 10-year periodic height increment of forest trees from height, diameter, diameter increment, and habitat type. Crown ratio was considered as an additional variable for prediction, but its contribution was negligible. Coefficients of the function were estimated for 16 species of trees growing in 10 habitat types of northern Idaho and northwestern Montana.

OXFORD: 561.1; 564. KEYWORDS: height increment, tree-growth models, western white pine, western larch, Douglas-fir, grand fir, western hemlock, western redcedar, lodgepole pine, Engelmann spruce, subalpine fir, ponderosa pine, habitat type.

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USDA Forest Service
Research Paper INT-164
Supplement 1
April 1975

Prediction of Height Increment For Models of Forest Growth

Albert R. Stage

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Forest Service

U.S. Department of Agriculture

Ogden, Utah 84401

Roger R. Bay, Director

During the preparation for publication of Research Paper INT-164 additional trees were obtained from the Colville, Clearwater, and Nezperce National Forests, from research studies of grand fir yield by the author, and from defect distribution studies by Dr. Arthur D. Partridge, College of Forestry, Wildlife and Range Sciences, University of Idaho.

Analysis of these 330 additional trees has provided better coverage of several species and habitats; as shown in the revised table 1. The newly derived coefficients for model (5) (pg. 12) are given in the revised table 5 and the computer subroutine provided in the appendix. The new estimate of the multiplier for removing bias due to the logarithmic transformation equals 1.107.

Table 1.--*Distribution of sample trees by species and habitat type*

Species	Habitat										Total
	Pseudotsuga/ Symphoricarpos	*Pseudotsuga/ Physocarpus*	*Pseudotsuga/ Calamagrostis*	*Abies grandis/ Pachistima*	*Thuja/ Pachistima*	*Tsuga heterophylla/ Pachistima*	*Abies lasiocarpa/ Pachistima*	*Abies lasiocarpa/ Xerophyllum*	*Abies lasiocarpa/ Menziesia*	*Abies lasiocarpa/ Vaccinium*	
Ponderosa pine	1	30		17	8						56
Douglas-fir	108	107	28	143	31	41	27	6		6	497
Western larch		9		17	14	27	4	14		2	87
Lodgepole pine		7	49	14	3	17	3	12	4	90	199
Grand fir				81	48	89	17	3		1	239
Western white pine				22	3	76		1		1	103
Western redcedar				1	52	39					92
Western hemlock					3	109	8				120
Engelmann spruce			2	2		3	3	6	7		23
Subalpine fir						9	16	42	11	1	79
Total	109	153	79	297	162	410	78	84	22	101	1,495

Table 5.--*Coefficients for estimating the logarithm of 10-year periodic height growth*

	Habitat									
	Pseudotsuga/ Symphoricarpos	*Pseudotsuga/ Physocarpus*	*Pseudotsuga/ Calamagrostis*	*Abies amabilis/ Rachitima*	*Tsuga/ Rachitima*	*Tsuga heterophylla/ Rachitima*	*Abies lasiocarpa/ Rachitima*	*Abies lasiocarpa/ Xerophyllum*	*Abies lasiocarpa/ Vaccinium*	*Abies lasiocarpa/ Carex*
					Intercept coefficient					
Ponderosa pine	2.4768	3.9227		3.4004	2.6014					
Douglas-fir	2.1560	3.6019	2.8472	3.0796	2.2806	2.9937	3.0606	1.9315		2.4721
Western larch		3.6605		3.1382	2.3392	3.0523	3.1192	1.9901		2.5307
Lodgepole pine		3.5812	2.8264	3.0589	2.2599	2.9730	3.0399	1.9108	1.7232	2.4513
Grand fir				3.2032	2.4042	3.1172	3.1842	2.0550		2.5956
Western white pine				3.3438	2.5448	3.2579		2.1957		2.7363
Western redcedar				2.7946	1.9956	2.7086				
Western hemlock					2.2455	2.9586	3.0255			
Engelmann spruce			2.7679	3.0003		2.9144	2.9813	1.8522	1.6646	
Subalpine fir						2.9458	3.0128	1.8836	1.6960	2.4242
					Variable coefficients					
Variable										
ln(ΔD+0.5)	.99173	.56944	.63363	.46651	.49104	.43979	.50854	.33112	.95970	.79813
ln(D)	-.35739	-.62543	-.64966	-.34633	-.09599	-.27165	-.36298	.05146	.02819	-.35941
ln(H)	-.09613	-.09613	-.09613	-.09613	-.09613	-.09613	-.09613	-.09613	-.09613	-.09613

```
      SUBROUTINE HTGT(ISP,IHAB,D,H,DD,D2,H2)
C
C        ISP IS SPECIES SUBSCRIPT
C        IHAB IS HABITAT SUBSCRIPT
C        D IS DIAMETER
C        H IS HEIGHT
C        DD IS 10-YEAR PAST DBH GROWTH
C        D2 IS NEW DIAMETER ONE YEAR HENCE
C        H2 IS THE NEW HEIGHT ONE YEAR HENCE
      DIMENSION ASPE(10),AHAB(10),BHAB(10),CHAB(10),BKR(10)
C
C           SPECIES SUBSCRIPT   DEFINITION
C                  1          WHITE PINE
C                  2          WESTERN LARCH
C                  3          DOUGLAS FIR
C                  4          GRAND FIR
C                  5          WESTERN HEMLOCK
C                  6          CEDAR
C                  7          LODGEPOLE
C                  8          SPRUCE
C                  9          SUBALPINE FIR
C                 10          PONDEROSA PINE
C
      DATA ASPE /-0.731950,-0.937502,-0.996132,-0.872584,-1.03127,
     1           -1.28118, -1.01687, -1.07542, -1.04398, -0.67530/
C
C           HABITAT SUBSCRIPT     DEFINITION
C                  1          PSEUDOTSUGA / PHYSOCARPUS
C                  2          PSEUDOTSUGA / SYMPHORICARPOS
C                  3          PSEUDOTSUGA / CALMAGROSTIS
C                  4          ABIES GRANDIS / PACHISTIMA
C                  5          ABIES LASIOCARPA / PACHISTIMA
C                  6          ABIES LASIOCARPA / XEROPHYLLUM
C                  7          ABIES LASIOCARPA / MENZIESIA
C                  8          ABIES LASIOCARPA / VACCINIUM
C                  9          THUJA / PACHISTIMA
C                 10          TSUGA HETEROPHYLLA / PACHISTIMA
C
      DATA AHAB /4.59802,3.15211,3.84330,4.07574,4.05676,
     1           2.92763,2.74002,3.46821,3.27674,3.98983/
C
      DATA BHAB /.56943679,.99173111,.63362795,.46651012,.50854200,
     1           .33111995,.95970452,.79812711,.49103850,.43978649/
C
      DATA CHAB /-0.62542897,-0.35739297,-0.64966339,-0.34632784,
     1           -0.36297816,.051463176,.028194819,-.35940510,
     2           -.095985949,-0.27164507/
C
      DATA DSP /-0.0961271/
C
      DATA BKR /1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09/
C
      D2 = SQRT(D**2 + DD * (2. * D - DD) * BKR(ISP) / 10.)
C
      H2 = H + EXP(ASPE(ISP) + AHAB(IHAB) + BHAB(IHAB) * ALOG(DD + 0.05)
     1     + CHAB(IHAB) * ALOG(D) + DSP * ALOG(H)) * 0.11066
      RETURN
      END
```

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FIRE RETARDANT
ROUND DISTRIBUTION PATTERNS
FROM THE CL-215 AIR TANKER

ARLES W. GEORGE

USDA FOREST SERVICE
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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
OGDEN, UTAH 84401
1975

USDA Forest Service
Research Paper INT-165
May 1975

FIRE RETARDANT GROUND DISTRIBUTION PATTERNS FROM THE CL-215 AIR TANKER

Charles W. George

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401
Roger R. Bay, Director

THE AUTHOR

CHARLES W. GEORGE was graduated from the University of Montana in 1964 in Forest Engineering. He received his master's degree at the University of Montana in 1969. In 1965, he joined the Northern Forest Fire Laboratory staff in Missoula, Montana, where he is now responsible for research dealing with forest fire retardant chemicals.

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ABSTRACT

Several fire retardants in current use were dropped from the Canadair CL-215 to determine drop height effects and for evaluation of the tank and gating system. This was accomplished through the quantification and analysis of the characteristics of the ground distribution patterns--such as retardant recovery and pattern contour lengths. The effects of retardant type, load size, drop height and speed, aircraft attitude, and drop conditions on the ground distribution patterns were also determined.

Drop height and load size were found to be the most significant variables, affecting almost all measured parameters for the retardants dropped. Covariance analysis of linear drop height models for total recovery indicated the greatest difference existed between the gum-thickened retardants (Phos-Chek XA and Gelgard) and the unthickened or clay-thickened retardants (Fire-Trol 100 and water). The Phos-Chek XA had the greatest recovery, followed by Gelgard, and then Fire-Trol 100 and water. Similar results for contour areas and line lengths occurred in the nonlinear models developed for predicting effects of drop height.

The data analysis indicated the optimum drop height for the gum-thickened Phos-Chek XA and Gelgard to be as much as two to five times higher than that for Fire-Trol 100 and water. Thus, effective drop heights and safety may be greatly increased by the use of gum-thickened retardant.

The conclusions made were supported by an analysis of drop times and evaporation losses which indicated that the gum-thickened retardants had smaller drop times, greater cohesion, longer stripping times, and a larger mean droplet size after erosion.

Evaluation of the tank and gating system of the CL-215 and comparison of its performance with that of other presently used aircraft indicate its line-building efficiency to be equally effective. The performance and flexibility of the CL-215 tank and gating system could be improved, however, if a four-tank or gate system incorporating an intervalometer were adopted rather than the manually sequenced two-gate system.

INTRODUCTION

In the past 20 years, it has become increasingly common practice to slow or contain forest fires by cascading water or fire-retarding chemicals on or ahead of the flames, while firefighters construct firelines. This attack system was first used operationally in 1956 when fire control agencies in southern California, using converted military surplus airplanes and modified crop dusters, dropped about one-quarter million gallons of water and retardant solutions on fires. By 1960, the "air tanker" had become an accepted fire suppression tool.

Over 20 million gallons of retardant were applied aerially to fires in the United States in 1973, mostly from World War II-type aircraft, such as the B-26, B-17, and PB4Y2, flying at very near treetop level. In an effort to improve and update the aircraft fleet, newer military surplus-type aircraft, such as the C-119, P2V, and S2F, are being considered as replacement aircraft. In addition, the Canadair CL-215 has now become available. Unlike other aircraft presently being used or considered, the CL-215 is a special-purpose amphibious aircraft specifically designed to scoop water while planing on the water surface. This technique permits rapid delivery of water on a fire because no landing and shut-down type is required. The aircraft can also be used, however, to deliver retardant from fixed land bases.

The drop pattern required by the fire conditions, and the characteristics of the delivery platform or aircraft, dictate the effective and minimum safe drop heights. The performance above this minimum safe drop height is related to the efficiency of the tank and gating system. Whether or not a particular system can deliver an effective drop pattern depends on the volume of retardant solution, the properties of the retardant, and its flow rate upon release from the aircraft. Flow rates are related to the tank geometry and venting system, the size and shape of the gates, gate opening speed and degree of obstruction, and the aircraft speed and flight envelope effect.

Therefore, to improve the drop efficiency and safety, while updating the present air tanker fleet, emphasis must be placed on tank and gating system design, the properties of the fire retardant, and the relation between these two. The probable performance of proposed tank and gating systems must be known in order to assure selection of the best aerial attack systems and to optimize their performance. Therefore, the study reported here assessed the performance of the tank and gating system of the CL-215. (It does not necessarily reflect on the performance of the CL-215 as an aerial platform, however.) Similarly, the properties of various retardants and their performance must be known. Thus, the study evaluated several retardants that are currently used.

A series of test drops was carried out with the following specific objectives:

1. To provide data on characteristics of retardants when dropped, and on ground distribution patterns, for the purpose of evaluating the tank and gating system of the CL-215.

2. To determine the relative differences in drop characteristics between currently used long-term retardants, onboard-mixed short-term retardants, and water.

3. To provide basic data primarily for related studies of retardant delivery mechanization dealing with the effect of aircraft drop height and drop size on ground patterns.

PROCEDURES

The influences on ground distribution patterns and thus on the effectiveness of any cascade retardant drop are:

1. The physical and chemical properties of each general type of retardant, and the specific characteristics of the retardant when dropped.

2. The aircraft tank and gating size and configuration, the speed of door-opening, venting, airflow characteristics around the gates, and other parameters affecting the behavior of the retardant when released.

3. The speed, drop height, and attitude of the aircraft as the drop is released.

4. The environmental conditions such as temperature, humidity, windspeed, and wind direction at the time of the drop.

Retardants

The retardants used in the evaluation were Phos-Chek XA, Fire-Trol 100, Gelgard, and water. Phos-Chek XA is a product of Monsanto Co., St. Louis, Missouri; Fire-Trol 100, Chemonics Industries, Inc., Phoenix, Arizona (formerly Arizona Agro-chemical Company); and Gelgard, Dow Chemical Co., Midland, Michigan. Phos-Chek XA and Fire-Trol 100 are long-term retardants; that is, besides building a blanket of water on fuels by means of a slurry, they chemically alter the pyrolysis and combustion reactions of the fuel so that smaller amounts of combustible products are formed. Thus, these two retardants retain considerable effectiveness after the water has completely evaporated from the slurry. They account for the majority of retardant currently dropped within the United States. Gelgard is a short-term retardant. It does not contain an active chemical but serves only to hold water in a viscous mixture, which theoretically shows better drop behavior than water. It also has better retention and forms an ablative layer on fuel surfaces. Gelgard was selected for the evaluation because it could be used for onboard thickening of salt-free water scooped by the CL-215.

Water was included in the tests because one of the prime attributes claimed for the CL-215 is its water-scooping and water-dropping capability. Water also serves as a baseline for comparing results of other studies.

The standard mixing proportions for these retardants were used in the test drops. These ratios and related physical-chemical characteristics of each fire retardant are given in table 1; for the composition of the formulations, see table 9 of Appendix I.

Standard mixing procedures and equipment were used to prepare the retardant solution Viscosity and salt content of the solutions were monitored frequently to assure quality control. Gelgard was mixed using an Aardvark disperser and was stored in a portable 1,000-gallon tank. Fire-Trol 100 was mixed in a high shear Lely mixer and was transferre to a 2,000-gallon holding tank. Phos-Chek XA was mixed using a portable air slide bin and a Monsanto-Hamp eductor. The mixed Phos-Chek XA was held in a 500-gallon saddle tank and a 3,000-gallon portable tank (fig. 1).

TABLE 1.--PHYSICAL-CHEMICAL CHARACTERISTICS OF SELECTED FIRE RETARDANTS[1/]

Retardant	Recommended use level	Viscosity[2/]	Density of slurry	Diammonium phosphate (DAP) $(NH_4)_2HPO_4$	Ammonium sulfate $(NH_4)_2SO_4$
	Lb/gal	*Centipoise*	*Lb/gal*	*Percent*	*Percent*
			LONG-TERM		
hos-Chek XA	1.14	1,500-2,000	8.9	10.6	
ire-Trol 100	2.78	1,500-2,500	9.4		15.6
			SHORT-TERM		
elgard	[3/] 0.024	800-1,200	8.33		
ater		1	8.33		

[1/] Data from National Fire Protection Association (1967) and George (1971b).

[2/] Measured by Brookfield Viscometer Model LVF at 60 r/min.

[3/] The required use-level of Celgard to provide a viscosity of 800-1,200 centipoise Brookfield spindle No. 4) can be from 0.015 to 0.035 lb/gal of water, depending on the ype and amount of water hardness.

Figure 1.--Retardant mixing equipment [illegible]

Simultaneous storage of the three retardant solutions and separate circulation and transfer pumps were desirable so that products could be randomly selected during the tests. The fill lines and CL-215 tanks were flushed with water before a new retardant was loaded. Problems caused by the sensitivity of Gelgard to contamination, water hardness, and storage in direct sunlight prevented completely randomized selection of retardants during the tests.

Tank and Gating System

The CL-215 tank system consists of two separate internal tanks with a capacity of 705.5 gallons each (600 Imperial gal), totaling 1,411 gallons. The capacity was determined with the tanks filled to the overflow or vent openings. For the test drops water was allowed to overflow, but retardants were not; although all loads were metered, control in the transfer system was such that the actual loads varied slightly (approximately ±10 gallons per tank). For computation and analysis purposes, loads of 700 gallons for a single tank drop and 1,400 gallons for a salvo drop were assumed. Either 700- or 1,400-gallon salvo drops or a 1,400-gallon sequential or "in-train" drop could be made. In the sequential drops the time interval between 700-gallon increments was at the discretion of the pilot.

One of the main objectives of the drop tests was to evaluate the CL-215 tank and gating system (fig. 2) through a detailed characterization of its drop performance. The dimensions of the tank and gating system and the time for door opening are the primary performance factors:

Gate opening: 31 by 61 inches (corners rounded) or 12.4 ft^2 per 700-gallon tank. Drop volume per unit area of gate opening: 56.5 gal/ft^2

Vent opening: 12-3/4 by 21 inches or 1.9 ft^2 per 700-gallon tank. Drop volume per unit area of vent: 376 gal/ft^2

Door-opening angle: 57° to 58.5° from fuselage (82° to 83.5° from horizontal)

Door-opening time: 0.5 s (single or salvo drop)

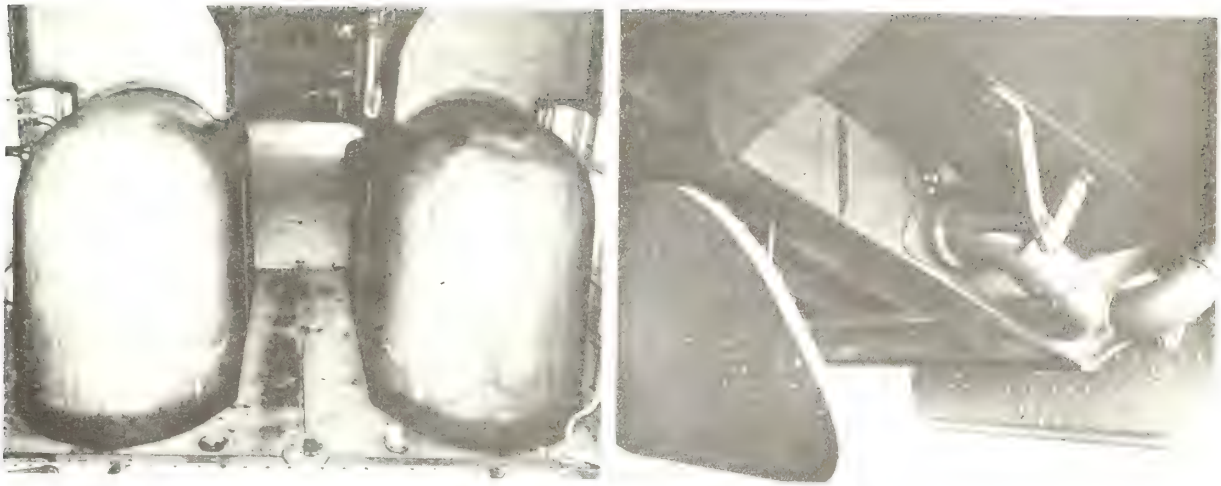
Release time: 0.75 s (single or salvo drop)

Experimental Design

DROP CONDITIONS

Drop heights of 150 and 300 feet, which are normally encountered under operational conditions, were selected for the tests. Some drops at heights of 500, 750, 1,000, 1,500, and 2,000 feet were also made to provide a data base for studying the effect of increasing drop height on ground distribution patterns and to determine upper effective drop height limits. The safe CL-215 operating range for drops, 90 to 135 knots, dictated drop speeds used in tests. In the Porterville drop test study made using the TBM "Avenger" (George and Blakely 1973) a change in drop speed from 100 to 125 knots had only insignificant effects on ground distribution patterns. Therefore, a drop speed of 105 knots was selected for a standard test condition and a minimal number of drops were made at 125 knots, slightly below the maximum safe speed.

Aircraft attitude was also thought to affect ground distribution patterns in that drop trajectory and history, and therefore drop patterns, are directly related to the attitude. Because this variable was difficult to quantify with existing equipment, the decision was made to hold the attitude constant by attaining desired drop heights far in advance of the release point. A few drops with changes in attitude were made by dropping in a bank, dive, and loft mode to determine the magnitude of the effect of



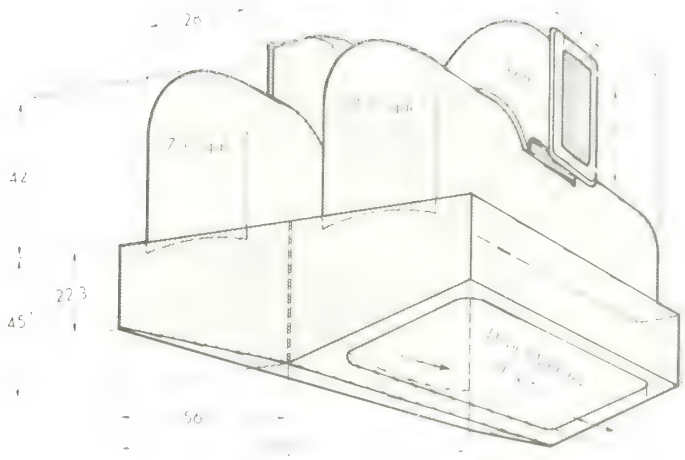


Figure 2.--CL-215 tank and gating system. Above left, *inside view of above-floor fiberglass tanks;* above right, *view of gates and water scooping snorkel;* below, *configuration and dimensions of the system.*

extreme differences in attitude on drop patterns. The effect of windspeed and wind direction, temperature, and relative humidity on drop patterns has been documented in previous studies (George and Blakely 1973) and thus no attempt to quantify these variables was made. It was hoped that drops could be made under wind conditions that would provide the least effect (<6 mi/h). A minimum temperature of 50°F and a maximum relative humidity of 50 percent were selected as condition goals for the study.

Test Matrix

After consideration of the objectives of the study and the influences on drop effectiveness, a test matrix (fig. 3) was selected that would provide maximum data on the performance of the CL-215 tank and gating system and quantify the influence of the variables while minimizing the number of drops performed.

The test matrix and a complete factorial design call for 320 drops. To reduce this requirement, it was decided that a minimum number of drops at 125 knots and in other than level flight would be performed. Also, it was recognized that as drop height increased, resulting average drop pattern concentrations would decrease to less than desirable levels (<1 gal/100 ft^2), and the drops at greater heights would not be necessary. With these limitations, approximately 75 drops would be required in a matrix that would lend itself to a multiple regression analysis and allow quantification of main effects and interactions. Significance of variables that were not factorialized in the matrix (aircraft speed, attitude) would be determined by comparison of means ("t" test).

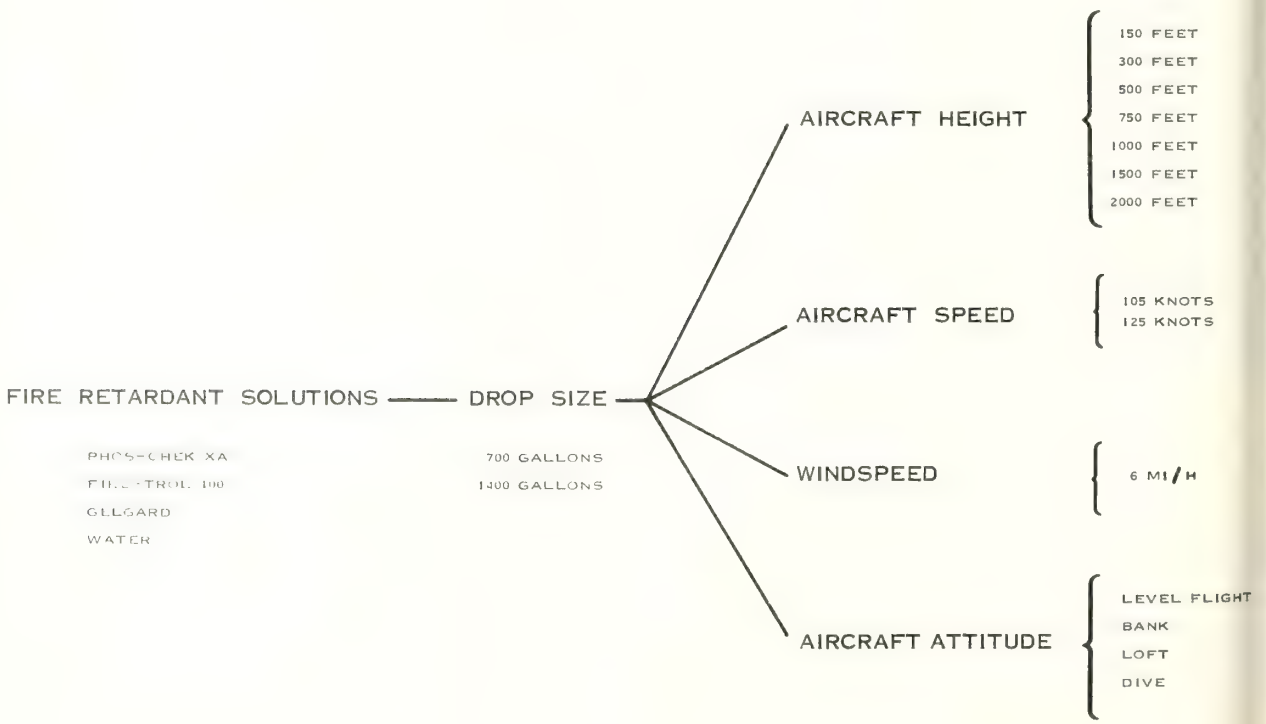


Figure 3.--Test matrix for the CL-215 tank and gating system evaluation.

MEASUREMENTS

The procedure used to sample and determine retardant characteristics, monitor environmental conditions during the drops, measure aircraft height and speed and retardant drop history, and determine ground distribution patterns was similar to procedures used in the Porterville retardant drop study (George and Blakely 1975). Minor changes made in some details are identified in the following discussion.

Retardant Properties

During the tests, samples were taken from the storage tanks and their quality was determined to assure uniformity in a standard mix at the recommended levels. The retardant was analyzed for salt content using the field method (George 1971b) and the viscosity was measured with the Brookfield Viscometer Model LVF at 60 r/min (National Fire Protection Association 1967; George and Hardy 1966). If deviations in the stored material occurred, proper adjustments could usually be made and the solution could be returned to a standard mix.

Before each drop, samples were taken from the aircraft and were similarly analyzed. In addition, a sample of this material was bottled and returned to the laboratory where the density was measured using a pycnometer and the salt content was chemically determined using the Kjeldahl method for nitrogen analysis (USDA Forest Service 1969). Only the viscosity and density of Gelgard were measured, as Gelgard forms a short-term salt-free solution.

After the drop had been made, a sample was taken by randomly consolidating the retardant received by several of the cups from the grid used for sampling ground distribution (described later in this paper). The composite sample was taken from more than 20 cups, after weighing. Its viscosity was recorded, and the sample was returned to the lab where its density and salt content were determined. The amount of water lost by evaporation during the drop was calculated from the difference in salt content before and after the drop. The weight of control samples handled under similar conditions was monitored; this indicated that evaporation before and after capping was insignificant. For the properties of each retardant used for each drop, the percent increase in salt content by evaporation, the corresponding water loss in gallons, and the percent of the original retardant drop that was lost due to evaporation, see Appendix I, tables 10-12.

Environmental Conditions

The environmental conditions monitored during the drop were windspeed, wind direction, temperature, and relative humidity. Wind measurements were made using a Teledyne Geotech Model 1657 wind system. The wind transmitter units were placed atop a 20-foot tower within 200 feet of the ground distribution grid. The transmitters were oriented in relation to the drop area and expected flight path so that the tailwind would be from 0°, a headwind from 180°, and a crosswind at right angles to the flight path from 90° and 270°. For the analysis, the wind direction was reduced to 0° to 180° left or right, because the effect of a crosswind was the same from either side at the same angle. Both windspeed and wind direction were recorded on strip chart recorders having a chart speed of 0.2 lineal inch per second. An event marker was used to denote the point at which the aircraft gates were opened and the point at which the first retardant hit the grid. Average windspeed and direction during the drop period were calculated from the recording.

Figure 4.--Wind station and weather shelter situated adjacent to the grid.

The temperature and relative humidity were read from a hygrothermograph and a thermometer positioned in a weather shelter adjacent to the wind station at the time of the drop (fig. 4).

For average windspeed and direction, temperature, and relative humidity for each of the retardant drops, by product, see Appendix I, table 13.

Aircraft Height, Speed, and Retardant Drop History

Using the pressure altimeter and airspeed indicator, the pilot attempted to attain the desired drop height and speed with the maximum accuracy possible. Because variations in both drop height and speed are inevitable, precise height measurements were made from movie film taken from a right angle with a 70-mm Hulcher camera and from the 16-mm film taken from a front view. The aircraft's flight path and its distance from the ground distribution grid center line were determined from the 16-mm film. The 70-mm film was inspected with a microscope and the release point identified. Using the aircraft length as a base scale, the vertical distance to the ground level was calculated. Tick marks, placed electronically on the 70-mm film at 1/100-s intervals were used to calculate the groundspeed at the point of release.

The time required for the retardant to flow from the tank for the drops was determined using the 70- or 16-mm film. The 16-mm film was used when the 70-mm film was inadequate, but only after a comparison of times calculated from the two different films revealed that variations were insignificant. From the 70-mm film, the retardant drop trajectory was followed and the horizontal and vertical distance traveled from the release point calculated (fig. 5). Calculations were not possible for those drops where the release was slightly premature or late, causing the release or empty point to be out of view of the stationary camera. The elapsed time from the release point to initial retardant touchdown and the time required for the retardant to settle to the ground were determined using 16-mm film and the framespeed. The CL-215 making a water drop over the grid is shown in figure 6.

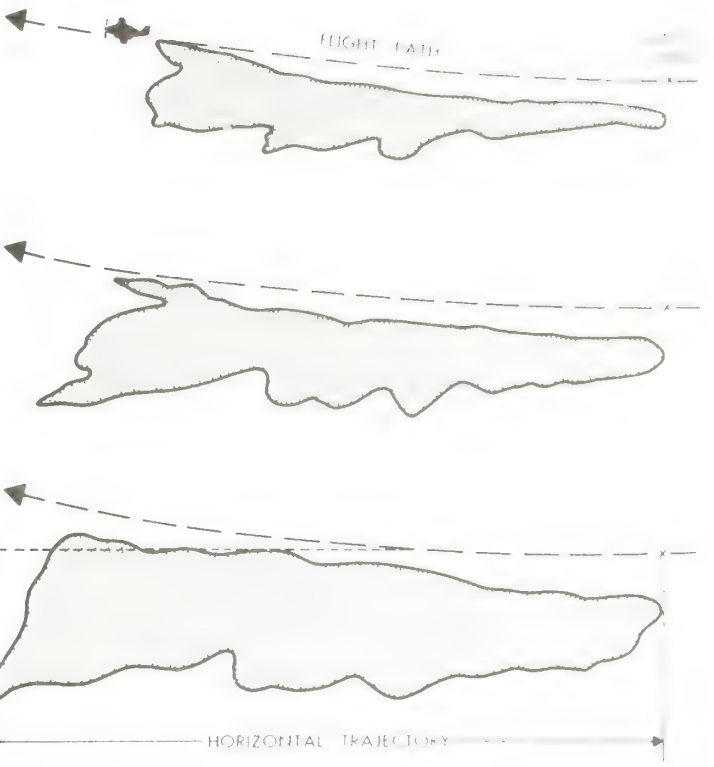


Figure 5.--Diagram showing the method for determining the horizontal and vertical trajectories.

Figure 6.--The YL-18 making a water drop over the grid.

For drop height, aircraft groundspeed, retardant exit time, time to the ground, time to settle, and drop trajectories, see Appendix I, tables 14-17.

Ground Distribution Patterns

The method used for measuring the ground distribution patterns for all drops consisted of a grid system of cups, each cup representing a definite area. The cups were collected and weighed to provide a measure of the concentration at each grid point Based on the results of previous drop studies (George and Blakely 1973; MacPherson 1967[1]), a grid which would best suit our expected drop dispersion patterns was laid out (fig. 7). The grid was divided into three portions: the inner grid containing 800

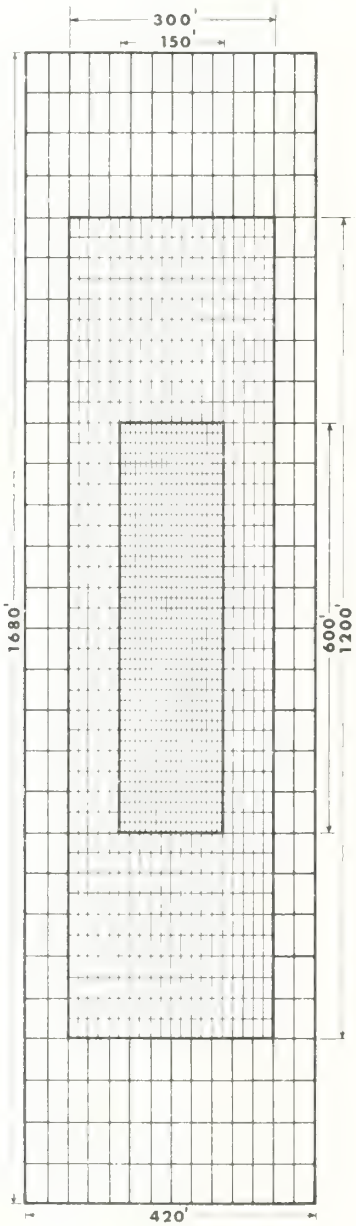


Figure 7.--Test grid. Cups are located at the center of each block. Inner grid, 800 blocks, each 7.5 by 15 feet; middle grid, 600 blocks, 15 by 30 feet; outer grid, 192 blocks, 30 by 60 feet.

[1]Also Joseph E. Grigel. Air drop tests with the Snow Commander Airtanker and Gelgard F Fire Retardant. Master's Thesis on file at the School of Forestry, Univ. Mont., Missoula. 80 p., illus. 1970.

points in an area 150 by 600 feet; the middle grid containing 600 points and extending the grid to 300 by 1,200 feet; and the outer grid containing 192 points and extending the overall grid to 420 by 1,680 feet. The inner grid was sampled most intensively because it was expected to collect the majority of the pattern area. Each point in the inner grid represented an area 7.5 by 15 feet or 112.5 ft^2. Points in the middle grid represented an area 15 by 30 feet or 450 ft^2 while the points in the outer grid represented an area 30 by 60 feet or 1,800 ft^2.

At each point within the inner grid and in the five adjacent rows of the middle grid, was a polyethylene cup, permanently fastened to the lid of a foot-actuated garbage can. An identical cup was placed inside the first cup as the retardant receptacle. A rubber band, slipped around and over the two cups, held the inner cup from being blown out by drops made from lower heights, or by wind or drop turbulence. The garbage can was fastened to the ground with two hairpin-type stakes. The distance from the ground to the top of the cup was approximately 19.5 inches, a height which would prevent dirt or debris from being splattered into the cup when lower drops were made. At the remaining points in the middle and outer grid, a cup was permanently fastened to a plate welded to the top of a steel rod. Each rod had an identification plate and a metal stop which kept the rod at the proper aboveground cup height when in place. Both types of cupholders and the general grid layout are shown in figure 8. The garbage-can-type cupholders provided a base for the cup and space for the cups to be stored following capping after a drop. This allowed as many as five drops to be made before a collection of the inner grid was needed. Cups held by the stake-type holder were collected after each drop.

The cups used in the grid were 25.52 in^2 in area (5.7 inches in diameter) and were identical to those used in the Porterville study (George and Blakely 1973). The polyethylene cups and lids were weighed, and then separated into 0.5-gram categories and color coded. Cups were chosen for use so that the color code indicated a particular drop during the day as well as the tare weight. This size cup requires that approximately 14 grams of retardant be received to equal a concentration of 2 gal/100 ft^2. The Porterville study included tests indicating that the cup depth was adequate to prevent splashout of the cups at the lower drop heights. In addition, tests indicated that the grid sampling was sufficient and provided a measure of the expected variation (that is, the standard deviation as a function of concentration for the inner grid: for coverages of 3 gal/100 ft^2 and less, a standard deviation of less than 0.2 gal/100 ft^2 can be expected).

After no more than five drops, the cups were collected in compartmented boxes designed to hold two or more grid rows (fig. 9). The boxes were then moved to the weighing area where several top-loading Mettler balances were set up. The weight of the cup and retardant (in grams) was recorded for each of the drops (fig. 10).

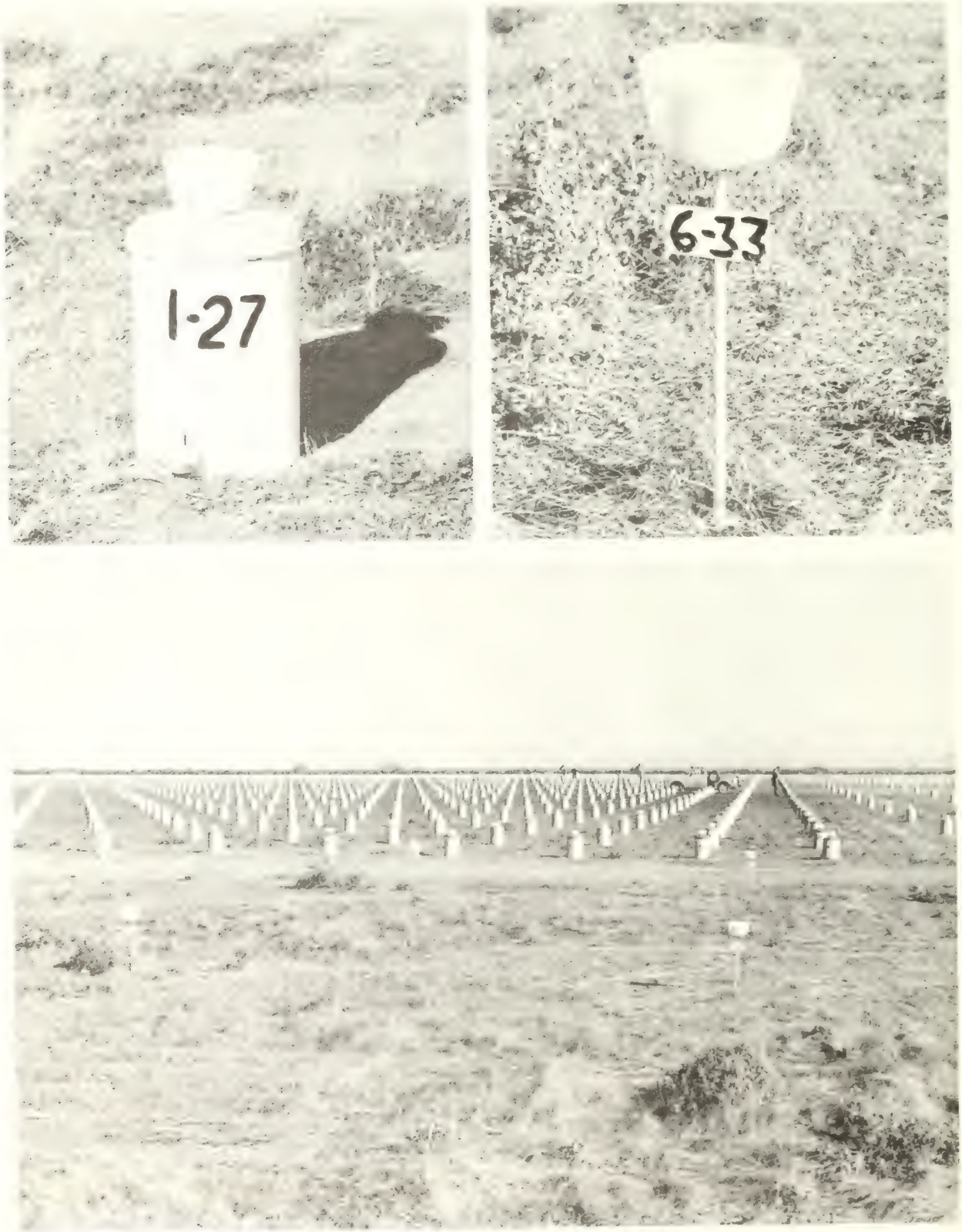


Figure 8.--The sampling method for ground distribution of retardant. Above, *types of cup holders used in the grid;* below, *general grid layout.*

Figure 9.--Collecting the cups following several [illegible].

Figure 10.--Weighing and recording weights of collected cups.

ANALYSIS AND RESULTS

Compilation of Grid Data

The basic grid data, the cup and lid tare weights, environmental data, retardant characteristics, and drop conditions were put on computer cards. The weight of the retardant collected was converted to volume per unit area--the most commonly used unit is gal/100 ft^2. The conversion was made using the formula

$$R = K \left[\frac{W-T}{d/A}\right]$$

where

R = retardant coverage (gal/100 ft^2)
K = conversion factor for units
W = weight of cup, lid, and retardant (g)
T = tare for cup and lid (g)
d = density of retardant (g/cc)
A = area of cup (25.52 in^2)

or

$$R = 0.1491 \left[\frac{W-T}{d}\right] \text{ gal/100 } ft^2.$$

Because the area represented by the inner, middle, and outer grid points varied, R was weighted in calculation of total volume as follows:

Inner grid points, volume = 1.125R gallons
Middle grid points, volume = 4.5R gallons
Outer grid points, volume = 18.0R gallons.

The total retardant reaching the grid was thus calculated as

Total retardant = Σ 1.125R inner grid points + Σ 4.5R middle grid points + Σ 18.0R outer grid points.

A computer program which summarized the grid data was set up. Volume of retardant recovered, in gallons per 100 ft^2, was calculated as a total for each of a series of concentration classes ranging from <0.02 to >5 gal/100 ft^2. The total area within each concentration class (area of coverage) was also calculated. A summary of these classes gives the total area covered and the total gallons recovered in the grid. A breakdown of areas and gallons by concentration class is provided in Appendix I, tables 18-25.

A computer program that would plot the concentration calculated for each grid point was developed. The plot was made to scale, with the decimal point for each concentration on the printout representing the location of the grid point. Using a method of linear proportioning, contour lines were hand drawn for concentrations of 0.2, 0.5, 1, 2, 3, and 4 gal/100 ft^2. From the distribution patterns, maximum lengths of the areas enclosed by the contour lines (to be called here "contour areas") for each concentration were determined. The 2 gal/100 ft^2 contour area is of special interest because studies of retardant effectiveness have shown that this is the minimum concentration that will produce a maximum reduction in the rate of spread, intensity, and radiation in a light fuel (0.5 lb/ft^2 or 11 tons/acre) when the retardant has lost all its moisture (George and Blakely 1972; USDA Forest Service 1969). The length of the 2 gal/100 ft^2 contour area with minimum widths of 5 and 10 feet, as well as the maximum contour area width, was measured. These 2 gal/100 ft^2 dimensions, as well as the lengths of each contour area, are given in Appendix I, tables 26-29.

Ground Pattern Responses

The criterion of drop effectiveness depends on the mode of retardant attack (direct or indirect) under actual conditions, and the strategy used (hotspotting, linebuilding, etc.). Either the length of adequate line built or the area of coverage and concentration for a drop may be the most important criterion. The value of a drop is always related, however, to the volume of retardant reaching the fuel. Thus, several ground pattern responses should be quantified and treated as dependent variables:

1. The total volume of retardant reaching the ground (recovery) and the distribution of this retardant per unit area;
2. The area of coverage at each concentration level; and
3. The dimension or length of each isoconcentration contour area.

The independent variables in the test matrix (fig. 3) were type of retardant, load size, drop height, aircraft speed, and aircraft attitude. The effect of wind, previously quantified in the Porterville study (George and Blakely 1973), was minimized and assumed constant because drops were made under low wind conditions. (The average windspeed for all drops was 5.8 mi/h; standard deviation $S_D = \pm 2.3$, standard error of the mean $S_m = \pm 0.26$.) Visual inspection of the data indicated that load size and drop height had the greatest effect on ground pattern responses (retardant recovery, area of coverage, and contour length). The ground responses were first plotted three dimensionally as a function of drop height and concentration for each retardant and load size. The aircraft speed, windspeed, and aircraft attitude for each point were then identified. Visual inspection of the data indicated that only aircraft speed had an effect of sufficient magnitude to cause the responses to fall outside the group data. On the basis of these plots, all responses except those for the few drops at higher aircraft speed (125 knots) were grouped, leaving type of retardant, load size, drop height, and aircraft speed as primary independent variables.

Retardant Recovery

Covariance analysis of the total retardant recovered as a linear function of drop height was undertaken for each type of retardant and load size. Results of the analysis suggest real differences existed between all retardants except Fire-Trol 100 and water. Phos-Chek XA gave the greatest recovery, followed by Golgard and then Fire-Trol 100 and water. The effect of load size on percent recovery was not significant except for water and for water and Fire-Trol 100 pooled. Lack of significance between load size for the other retardants probably reflected a variation within the data that was as great or greater than the influence of real differences in load size. In figure 11, the effect

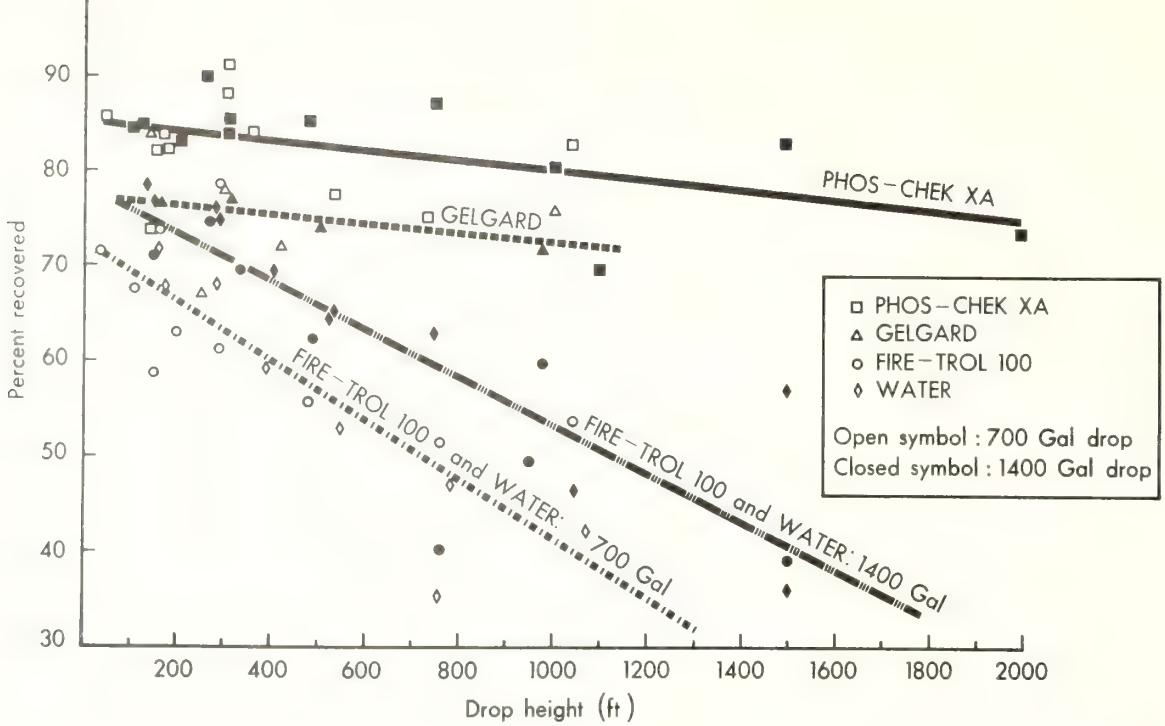


Figure 11.--Effect of drop height on percent of total retardant reaching the ground.

of drop height on total recovery, and the magnitude of differences between retardants are indicated by a plot of the actual drop data. The linear equations and the R^2 values (coefficients of multiple determination) indicating their goodness of fit, the data limits, and the results of tests for significance of differences between retardants are given in table 2. Predictions for the equations were calculated (table 3). In these predictions of total recovery (percent) for Phos-Chek XA and Gelgard, the two load sizes were pooled in the equations because load size did not cause a significant difference in recovery. For water and Fire-Trol 100, predictions were made from equations pooling drops of load size for Fire-Trol 100 and water for each load size, because 700-gallon drops of Fire-Trol 100 and water pooled were significantly different from 1,400-gallon drops of both retardants pooled.

Although the volume of retardant recovered is strongly indicative of effectiveness, the manner of distribution of this retardant is also important. The amount of retardant within concentration classes at increments of 0.5 gal/100 ft^2 was plotted against drop height. Visual inspection revealed that relationships were nonlinear and thus smooth curves in accord with expectation were fitted through these points. Because real differences in total retardant recovered for each type of retardant and load size appeared to exist in the simple linear models of the relationship, an algebraic portrayal of the drop height-retardant concentration (distribution) interaction was undertaken for each retardant and load size.[2/] The algebraic models for the distribution are given in Appendix II in the form of FORTRAN IV statements for simplicity.

[2/]This method is similar to the one used by George and Blakely (1973) in the Porterville study in an analysis of retardant drop patterns and drop characteristics. For each retardant and load size, expected algebraic forms as a function of drop height for concentration classes $\geq$0.2, $\geq$1.0, $\geq$1.5, $\geq$2.0, etc., to $\geq$4.0 gal/100 ft^2 were fitted to the data by approximate least deviations. These resulting curves were described and formulated as surfaces using algebraic forms identified from Matchacurves I and II (Jensen and Homeyer 1970, 1971). An algebraic portrayal of the retardant recovered within a concentration contour area greater than or equal to each concentration level as a function of drop height was thus developed.

TABLE 3.--PREDICTIONS OF TOTAL RETARDANT RECOVERED AS A FUNCTION OF DROP HEIGHT FOR FOUR RETARDANTS

Drop height	Retardant			
	Phos-Check XA	Gelgard	Fire-Trol 100 or water	
			700-gallon drop	3,100-gallon drop
	Percent			
150	84	76	68	75
300	84	76	64	71
500	82	75	58	66
750	81	74	51	59
1,000	80	72	43	51
1,500	77	70	30	41
2,000	74	68	17	25

$$\text{Percent recovered} = b * YP * \left\{ \frac{e^{-\left|\frac{6000 - DH}{XP} - 1\right|^{N}} - e^{-\left(\frac{1}{1 - I}\right)^{N}}}{1 - e^{-\left(\frac{1}{1 - I}\right)^{N}}} \right\}$$

where:

$b = 0.9898$

$XP = 6000$

DH = Drop height (ft)

C = concentration (gal/100 ft^2)

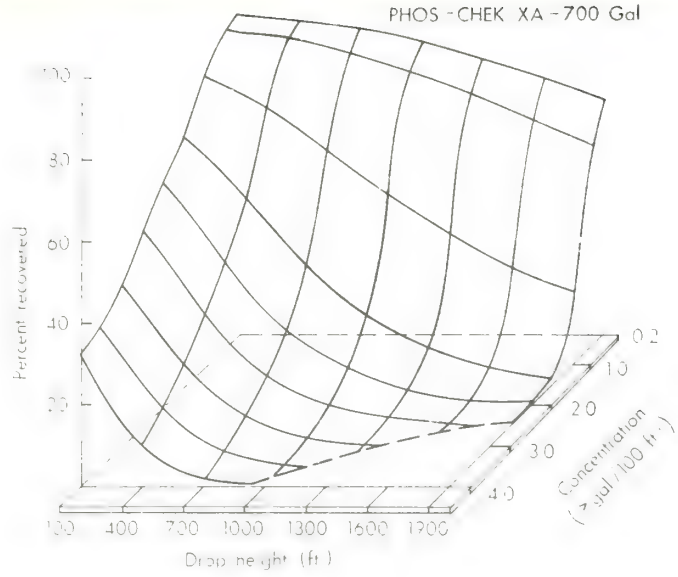
$$n = 1.45 + 0.55 * \left[\frac{e^{-\left|\frac{4 - C}{3} - 1\right|} - 0.00479}{0.9955} \right] - 2.728 \times 10^{-13} * (4 - C)^{20}$$

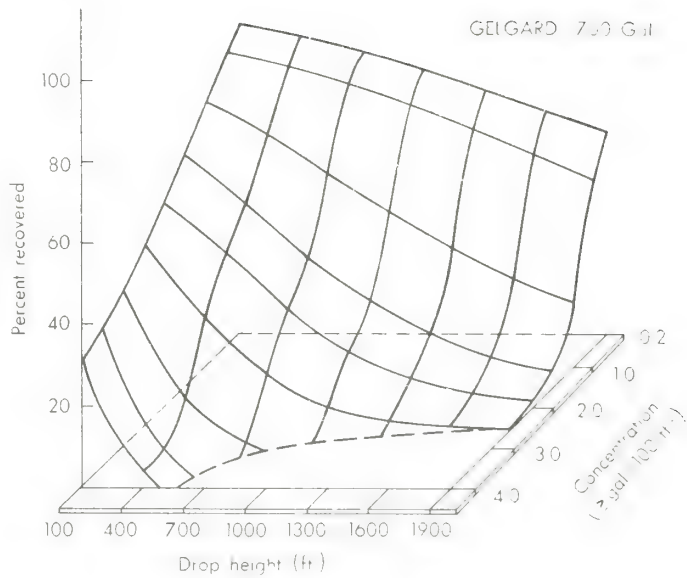
$$I = 0.915 - 0.0401 * (4 - C)^{1.64} - 0.4868 \left[e^{-\left|\frac{4 - C}{3.8} - 1\right|^{1.8}} \right]$$

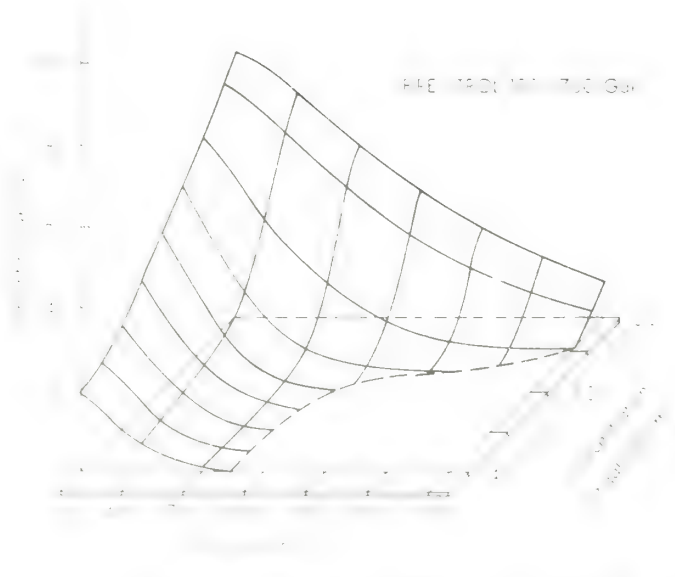
$$YP = 64.9 + 5.525 * (4 - C)^{0.82} + 4.892 \left[e^{-\left|\frac{4 - C}{4} - 1\right|^{1.5}} \right]$$

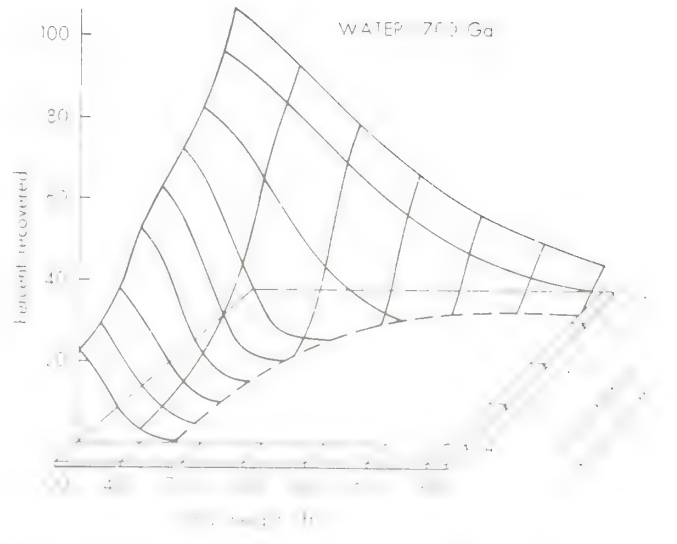
Figure 12.--The equation developed for the interaction between drop height and retardant distribution for 1,400-gallon drops of Phos-Chek XA.

The equation corresponding to the FORTRAN IV statement for 1,400-gallon Phos-Chek XA drops (fig. 12) illustrates the algebraic form of the interaction. Graphic forms for these models are shown in figures 13 and 14. Predicted values for the surfaces have been calculated and are presented in Appendix I, tables 30-33. Note that predictions of total recovery from the linear total recovery equations are somewhat larger than predictions from the algebraic distribution models at the >0.2 gal/100 ft^2 concentration level. The difference in predicted values is the amount of retardant falling in a trace category (0 to <0.2 gal/100 ft^2 concentration). Appendix I, table 34, gives the R^2 value at various concentration levels and the standard error of the estimate ($s_{y \cdot x_i}$) for each of the algebraic models for retardant and load size. (Note that an unknown number of degrees of freedom have been sacrificed in the development of the model surfaces, so that fairly strong data trends could be made evident. As a result, the estimates of the $s_{y \cdot x_i}$ may be conservative here.)


PHOS-CHEK XA-700 Gal
Percent recovered
100
80
60
40
20
0.2
1.0
2.0
3.0
4.0
Concentration
(gal/100 ft²)
100
400
700
1000
1300
1600
1900
Drop height (ft)


GELGARD 700 Gal
Percent recovered
100
80
60
40
20
0.2
1.0
2.0
3.0
4.0
Concentration
(gal/100 ft²)
100
400
700
1000
1300
1600
1900
Drop height (ft)


700 Gal


WATER 700 Gal
100
80
40

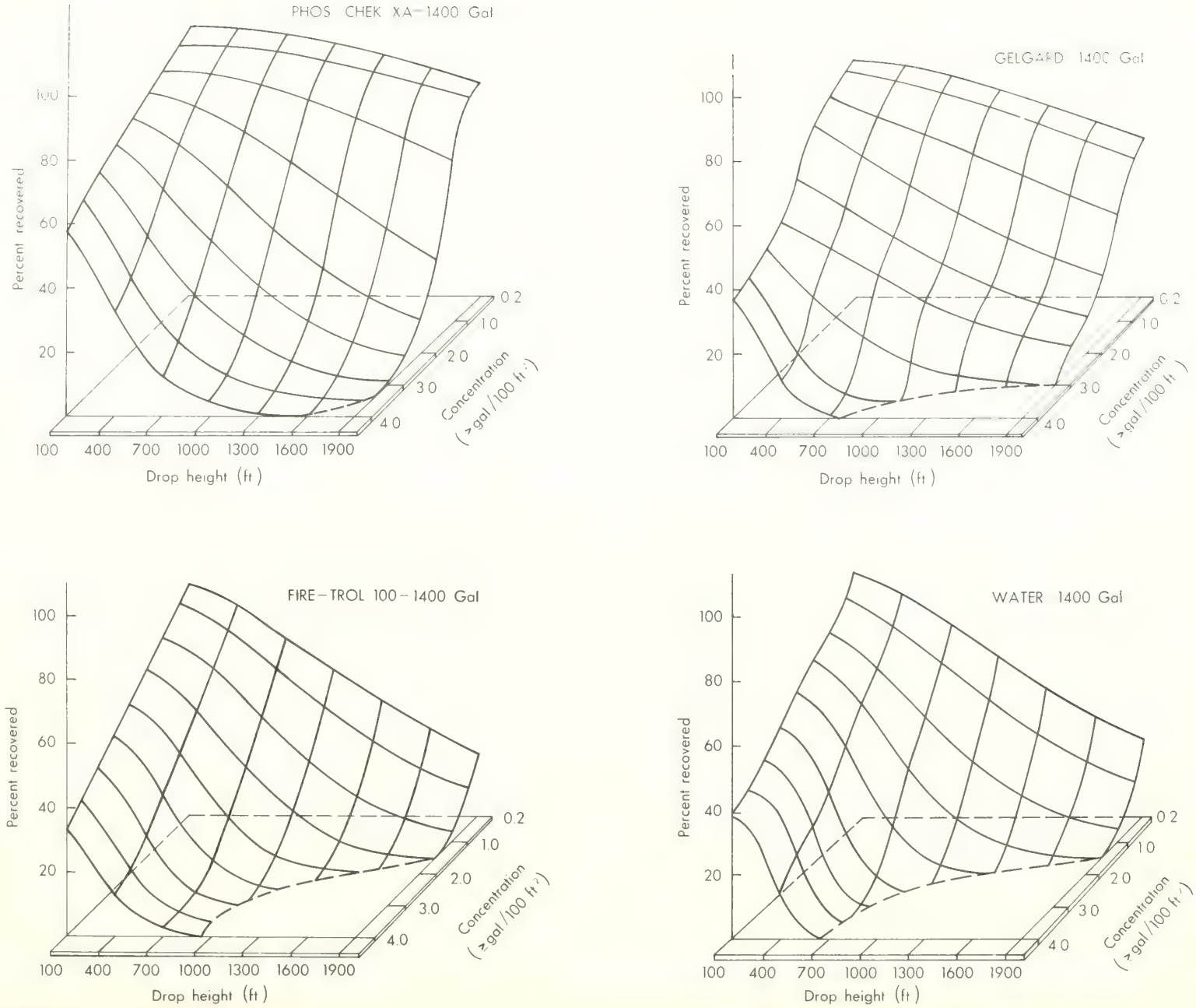


Figure 14.--Three-dimensional models for the distribution of 1,400-gallon drops of the four

Area of Coverage

The method used for analyzing the distribution of retardant reaching the ground was also used for analyzing the areas of coverage. Visual inspection of the data revealed large differences in the areas covered at different concentrations, as a function of load size. In areas of coverage, the differences between the retardants as a function of drop height appeared greater than the previously determined differences in retardant recovery by concentration level, as a function of drop height.

Load size obviously had a strong influence on area covered at selected concentration levels; the effect was much more pronounced than that of load size on percent recovery and distribution. Thus, models to predict area of coverage would require drop height and concentration level as independent variables for each type of retardant and load size. To predict areas of coverage at various concentration levels as a function of drop height, algebraic equations (models) were developed for each retardant and load size.

From the algebraic models, which are given as FORTRAN IV statements in Appendix II, for each retardant and load size, predictions of area of coverage were made (tables 35-38); graphic forms of these models were drawn and are shown in figures 15 and 16. Table 39 gives the R^2 values at various concentration levels and the standard error of the estimate ($s_{y \cdot x_i}$) for each of the retardant and load size models. The three-dimensional models for area of coverage at each concentration level, as a function of drop height, show the magnitude of differences between both drop size and type of retardant. From the predictions, the drop height providing the maximum area of coverage at 0.2, 1, 2, 3, and 4 gal/100 ft^2 was determined. These drop-height values clearly illustrate the difference in drop characteristics of the retardants and the effect of load size (table 4).

The 2 gal/100 ft^2 concentration level previously discussed as a minimum effective concentration falls approximately in the center of the range of concentrations for all model surfaces (fig. 13-16); whereas, the 4 gal/100 ft^2 level is the upper concentration limit on these surfaces. Drop patterns from presently used aircraft[3/] that are known to perform effectively under operational conditions, as well as the patterns from the CL-215, show that only small areas of concentration greater than 4 gal/100 ft^2 occur. It can, therefore, be rationalized that the 2 and 4 gal/100 ft^2 concentration levels are appropriate limits at which the performance of different retardants and tank and gating systems can be compared.

Assuming 2 and 4 gal/100 ft^2 to be effective concentrations in specific situations, depending on the fire, fuel, topography, weather, etc., some conclusions on effective drop heights can be made. Effective 700-gallon drops of Phos-Chek XA, for example, can be made from 100 to 600 feet if coverage of 8,400 to 8,900 ft^2 at 2 gal/100 ft^2 is adequate (with winds averaging 5.8 mi/h). If 4 gal/100 ft^2 are required, drop heights of 100 or 150 feet will provide 2,700 to 3,000 ft^2 of coverage. Drop heights can be greatly increased with larger drop sizes. Areas of coverage of between 16,000 and 23,000 ft^2 at the 2-gallon concentration level can be attained with 1,400-gallon Phos-Chek XA drops at any drop height between 100 and 1,400 feet; the maximum occurs at 806 feet (23,413 ft^2 of ≥2 gal/100 ft^2 coverage). If 4 gal/100 ft^2 concentrations are needed, 6,500 to 7,500 ft^2 of coverage can be achieved at drop heights between 100 and 500 feet (the maximum occurs at 200-foot drop heights). Water or Fire-Trol 100 can only approach the lower portion of this range of areas of coverage at drop heights near or below 200 feet.

3/ Drop pattern data from 1972 Marana drop test. Data on file at the Northern Forest Fire Laboratory, USDA Forest Service, Missoula, Montana.

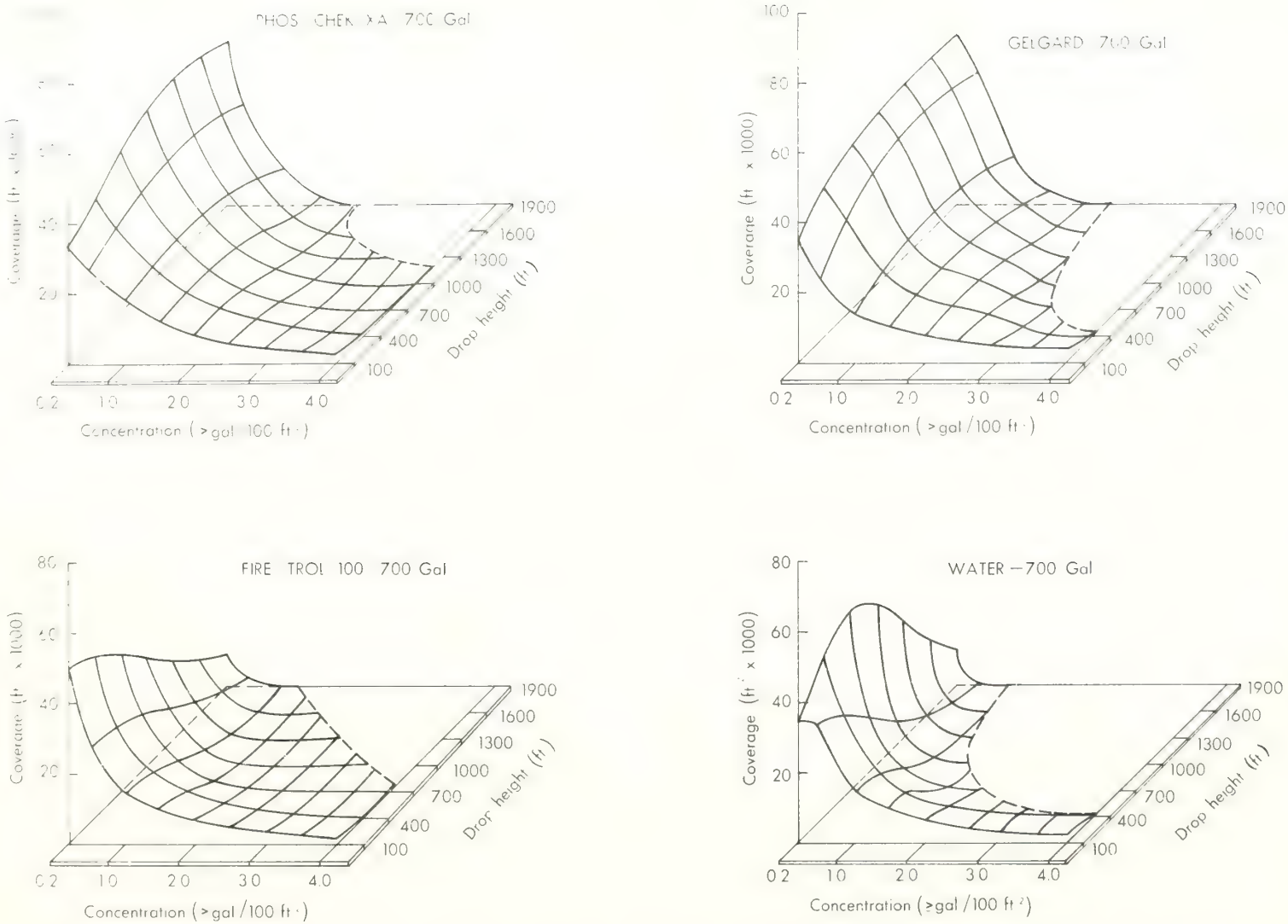
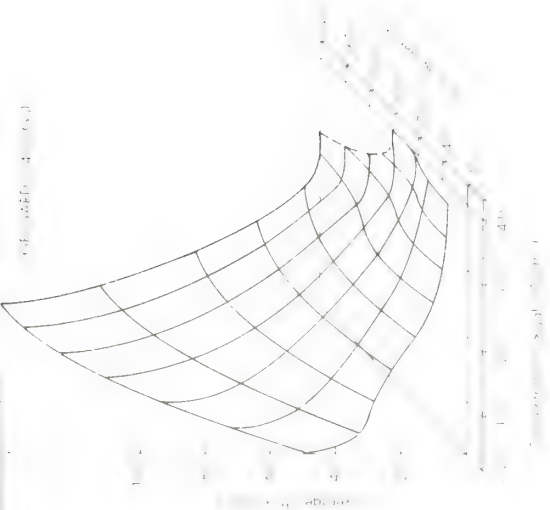
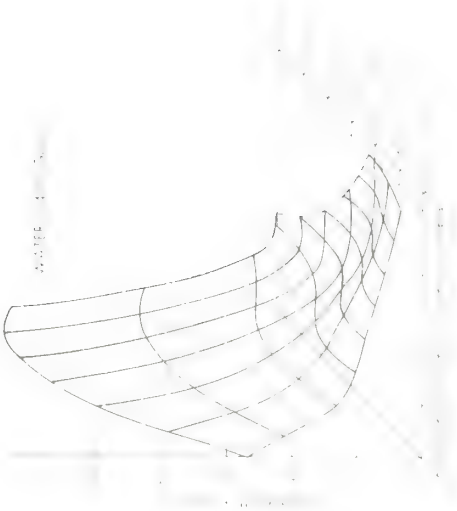


Figure 15.--Three-dimensional models for the area of coverage by 700-gallon drops of the four retardants, as a function of drop height and level of concentration.





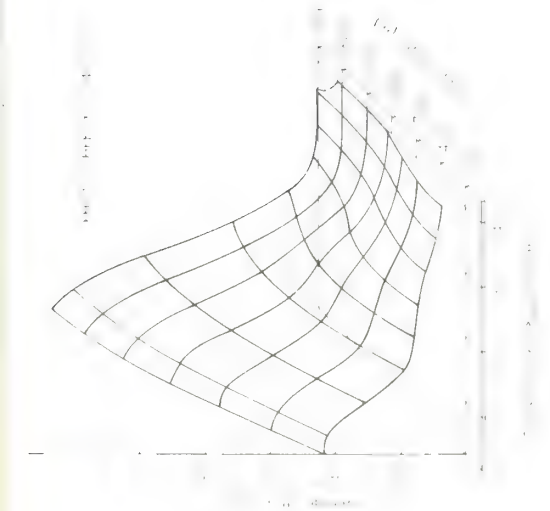


TABLE 4.--DROP HEIGHTS PRODUCING THE MAXIMUM COVERAGE FOR EACH OF FOUR RETARDANTS AND TWO LOAD SIZES, BY CONCENTRATION LEVEL[1/]

Concentration level (gal/100 ft²)	Phos-Chek XA		Gelgard		Fire-Trol 100		Water	
	Drop height	Max. area covered	Drop height	Max. area covered	Drop height	Max. area covered	Drop height	Max. area covered
	Ft	Ft²	Ft	Ft²	Ft	Ft²	Ft	Ft²
				700-GALLON LOAD				
0.2	1,314	51,983	1,400	49,810	150	49,517	697	50,748
1	733	20,598	1,007	20,677	150	14,482	150	14,522
2	268	8,994	404	8,711	150	7,020	150	6,936
3	150	4,715	150	5,143	150	3,083	150	3,234
4	150	2,688	150	3,367	150	1,500	150	2,124
				1,400-GALLON LOAD				
0.2	2,000	82,160	1,750	98,851	2,000	77,286	1,273	94,710
1	1,598	54,507	1,250	42,898	586	29,977	595	30,863
2	806	23,413	701	19,615	150	14,860	163	17,817
3	288	12,739	352	8,705	150	9,480	150	11,718
4	200	7,634	150	5,895	150	5,627	150	7,166

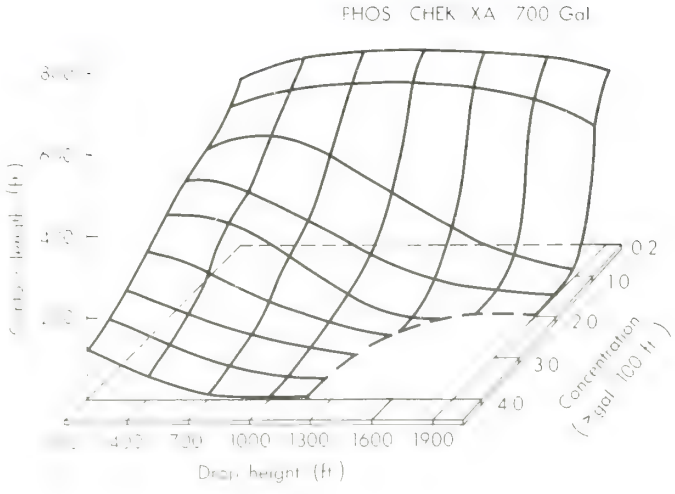
[1/] A minimum drop height of 150 feet is given because this height was generally near the lower drop test limits for each retardant. In comparing areas of coverage between retardants at a particular concentration level (horizontally), note the difference in corresponding drop heights.

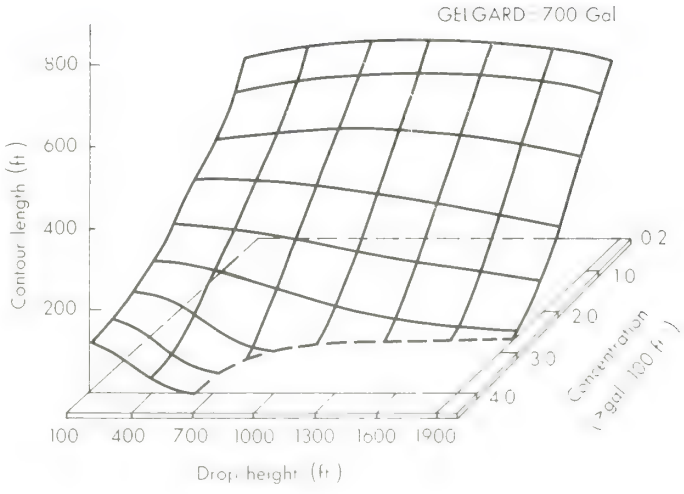
Contour Area Lengths

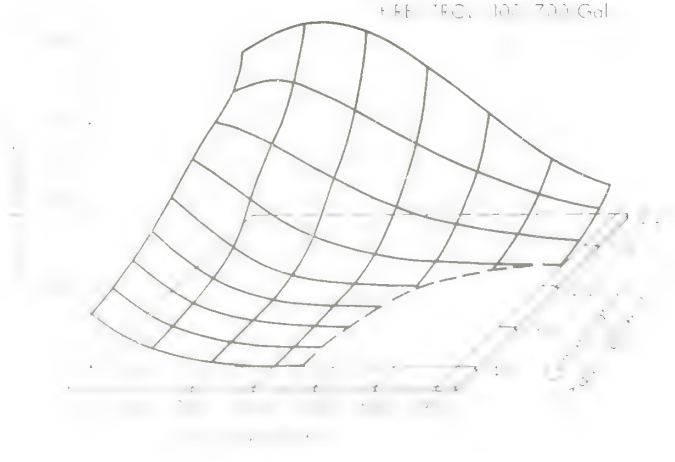
The maximum length of contour areas was analyzed as a function of drop height at the ≥ 0.2, ≥ 1, ≥ 2, ≥ 3, and ≥ 4 gal/100 ft^2 concentration levels. Since real differences existed in the total recovery covariance analysis for the different retardants and load sizes, it was assumed that real differences would also be found for these variables in the contour length analysis.

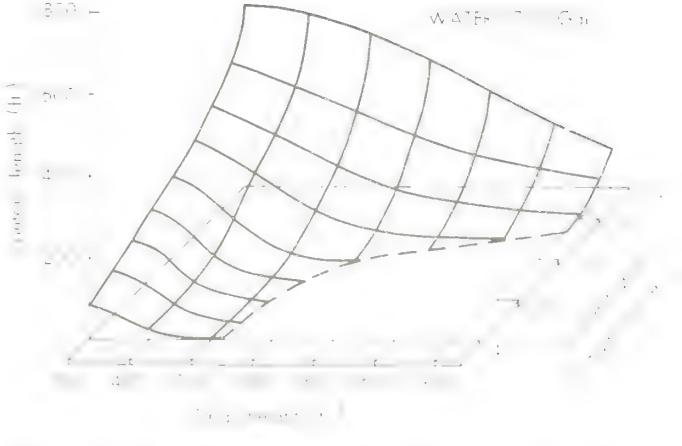
The contour area lengths for each concentration class were plotted over drop height and smooth curves in accord with expectation were fitted through these points. Inspection of these relationships revealed them to differ by type of retardant and load size. Thus again, an accurate algebraic portrayal of the drop height-contour length interaction was undertaken for each retardant and load size.

The algebraic models (Appendix II) are shown graphically in figures 17 and 18 and predictions from these models are given in Appendix I, tables 40-43. The R^2 values at various concentration levels and the standard error of the estimate ($s_{y \cdot x_i}$) for each retardant and load size model are given in table 44. The results of the analysis and a comparison of predictions suggest that in most situations the gum-thickened Phos-Chek XA produces longer pattern lengths (especially at concentrations of 1 to 4 gal/100 ft^2, which are usually necessary to provide effective coverage--table 5). Phos-Chek XA also produces tighter patterns (larger percentage of the higher concentration levels relative to the total pattern areas) as compared to the other retardants used in the drop tests.


PHOS CHEK XA 700 Gal
Contour length (ft)
800
600
400
200
0.2
1.0
2.0
3.0
4.0
Concentration
(gal/100 ft²)
100
400
700
1000
1300
1600
1900
Drop height (ft)


GELGARD 700 Gal
Contour length (ft)
800
600
400
200
0.2
1.0
2.0
3.0
4.0
Concentration
(gal/100 ft²)
100
400
700
1000
1300
1600
1900
Drop height (ft)





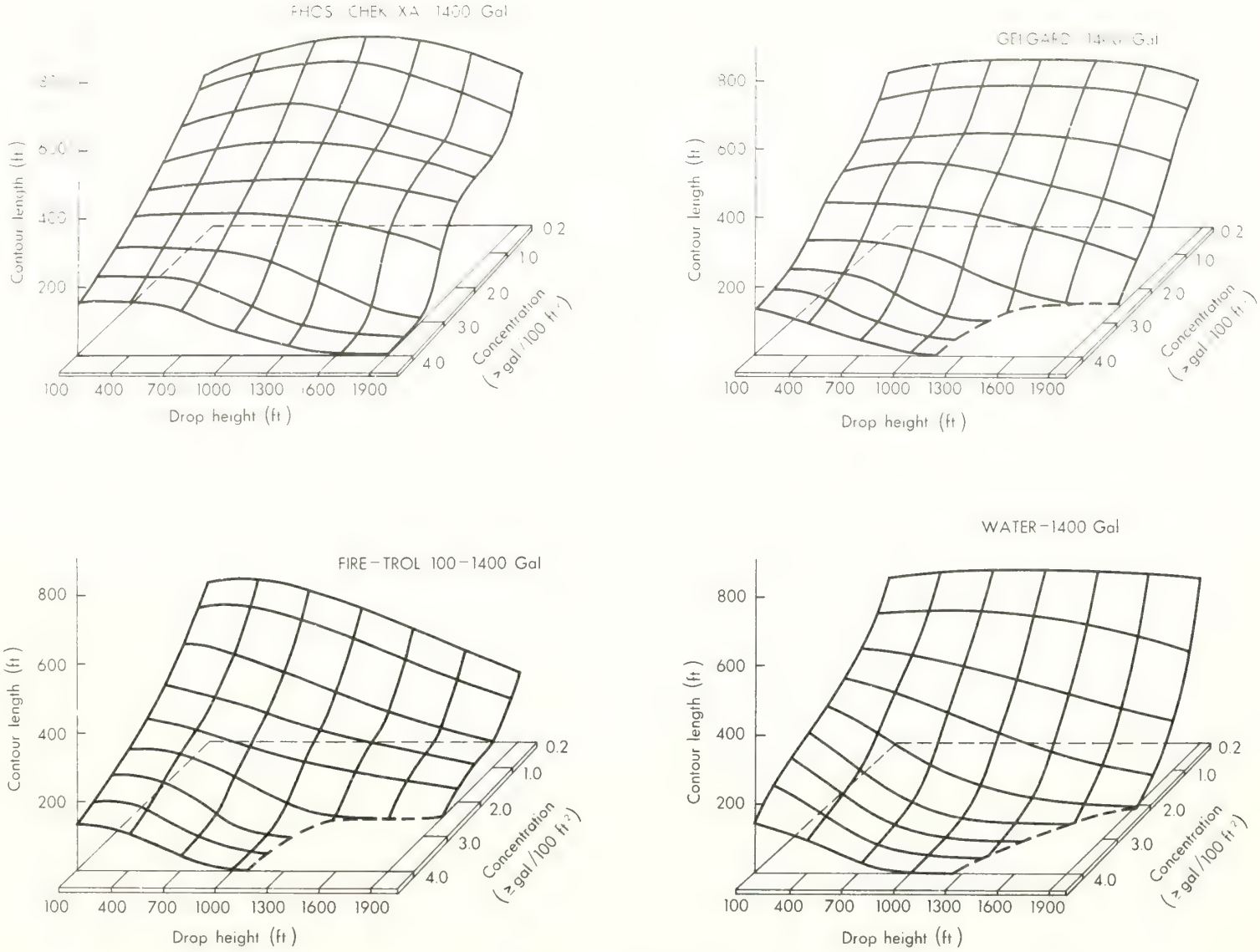


Figure 18.--Three-dimensional models for contour area lengths of 1,400-gallon drops of the four retardants, as a function of drop height and level of concentration.

TABLE 5.--DROP HEIGHTS PRODUCING MAXIMUM LENGTH OF FIRELINE FOR EACH OF FOUR RETARDANTS AND TWO LOAD SIZES, BY CONCENTRATION LEVEL[1/]

Concentration level (gal/100 ft²)	Phos-Chek XA		Gelgard		Fire-Trol 100		Water	
	Drop height	Line length	Drop height	Line length	Drop height	Line length	Drop height	Line length
	Feet							
	700-GALLON LOAD							
0.2	1,050	470	1,000	481	500	466	150	439
1	347	345	808	341	150	298	150	262
2	150	257	150	211	150	198	150	194
3	150	175	150	141	150	144	150	137
4	150	120	150	110	150	114	150	77
	1,400-GALLON LOAD							
0.2	1,000	548	1,000	483	300	461	150	479
1	700	435	807	341	150	352	150	358
2	898	313	197	240	150	235	150	277
3	399	215	150	149	150	172	150	222
4	300	159	150	128	150	126	150	141

[1/] A minimum drop height of 150 feet is given because this height was generally near the lower drop test limits for each retardant. In comparing areas of coverage between retardants at a particular concentration level (horizontally), note the difference in corresponding drop heights.

Visual inspection indicated that contour area lengths at the lower concentrations (0.2 and 0.5 gal/100 ft²) increased with the relatively small increase in aircraft drop speed (105 to 125 knots); whereas, the contour area lengths at higher concentrations (>2 gal/100 ft²) tended to decrease. Variation in the data for the limited number of high-speed drops of each retardant precluded development of a model or adequate statistical testing.

One method commonly used for increasing the length of continuous effective ≥2 gal/100 ft² contour areas is to sequence drop increments at a selected time interval. Several of these sequential drops were made during the tests and are designated as trail drops in Appendix I, tables 14-17. The ≥2 gal/100 ft² contour areas were used for drop pattern comparison and are given in table 6. Assuming symmetry of contour areas and general pattern geometry, a maximum theoretical contour area length can be calculated. For a given drop height and retardant, the ≥1 gal/100 ft² and ≥2 gal/100 ft² contour area length (c.a. length) can be predicted from the mathematical contour area length model developed. If two 700-gallon drop patterns were overlapped properly, the 1-gallon portions of each pattern would provide additional >2 gal/100 ft² c.a. length. For example:

≥2 gal/100 ft² c.a. length (sequential drop) = 2 (c.a. length ≥2 gal/100 ft²)

+ ½[(c.a. length ≥1 gal/100 ft²) - (c.a. length ≥2 gal/100 ft²)]

For a 700-gallon Phos-Chek XA drop from 100 feet:

≥1 gal/100 ft² c.a. length = 319 feet

≥2 gal/100 ft² c.a. length = 257 feet.

The maximum predicted contour area length (≥2 gal/100 ft²) would be:

2(257) + ½(319 - 257) = 545 feet.

TABLE 6.--PREDICTED AND ACTUAL CONTOUR AREA LENGTHS FOR SEQUENTIAL AND SALVO DROPS OF THREE FIRE RETARDANTS

Retardant and drop number[1/]	Drop height	Gate interval[2/]	Predicted contour area length ≥2 gal/100 ft^2 for load sizes of[3/]			Actual contour area length ≥2 gal/100 ft^2 for 1400 gal sequential loads[4/]
			700 gal	1400 gal	700 gal×2	
	Feet	*Seconds*	*Feet*			
Phos-Chek XA	100		257	274	545	
	200		255	284	550	
	300		249	292	545	
3	110	1.75				499 (2)
35	208	.92				408 (2)
52	316	.24				329 (1)
64	313	.17				291 (1)
Fire-Trol 100	100		219	239	479	
	200		175	229	408	
	300		131	217	331	
34	183	.67				305 (1)
62	165	1.33				375 (3)
63	340	.57				275 (2)
Water	100		203	311	440	
	200		181	289	397	
	300		144	260	336	
33	286	.38				218 (1)
39	137	1.04				465 (1)

[1/] Gelgard data have not been included since no sequential drops of Gelgard were made.

[2/] The gate interval in seconds is the time elapsed between initiation of the first and second load increment of sequential drops.

[3/] Predictions of contour area length are taken from the mathematical models (Appendix I, tables 40, 42, and 43) for sequential drops, length is calculated using 700-gallon drop predictions and the formula:
≥2 gal/100 ft^2 c.a. length (sequential drop) = 2(c.a. length ≥2 gal/100 ft^2) + 1/2[(c.a. length ≥1 gal/100 ft^2) -(c.a. length ≥2 gal/100 ft^2)].

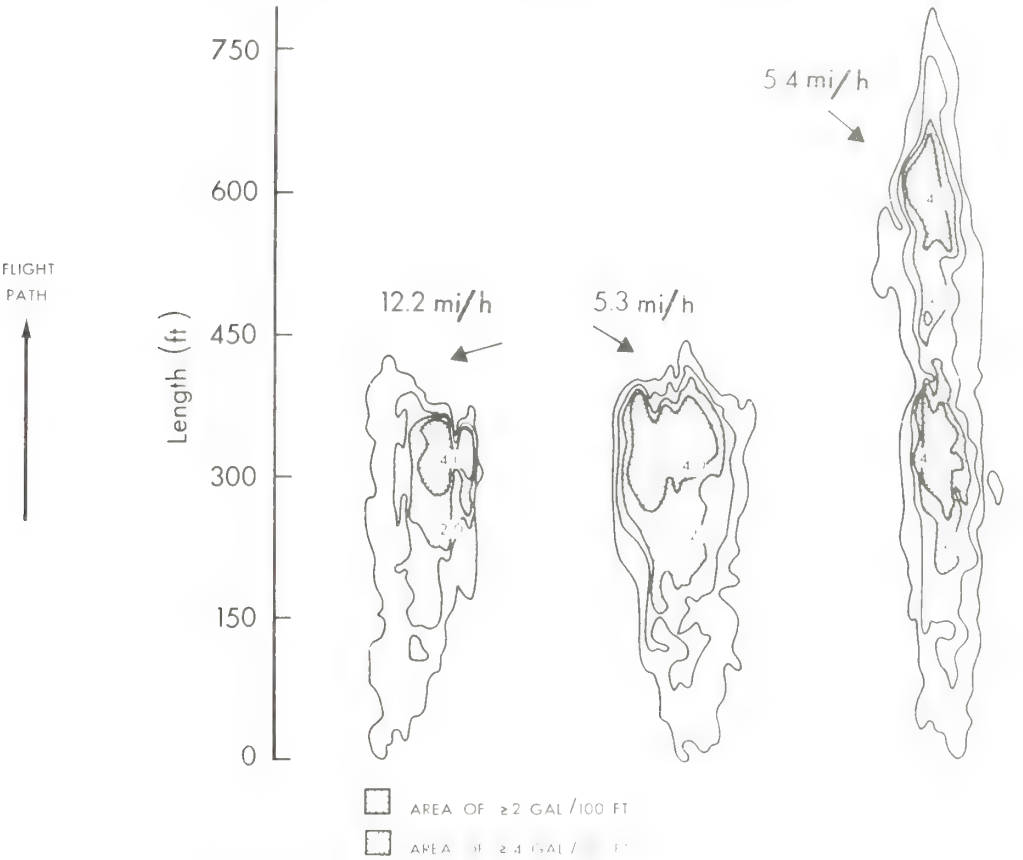
[4/] The number in parentheses adjacent to the actual ≥2 gal/100 ft^2 contour area length indicates the number of units providing this length; (1) indicates a continuous contour.

Note that the above equation predicts contour area lengths that are slightly longer than actual lengths at the lower drop heights, but makes fairly accurate predictions for higher drops. The contour lines for lower drop heights are closer together at the forward portion of the drop, because of a change in drop pattern geometry as a function of drop height. At low drop heights the patterns are elliptical--being much longer than they are wide. As drop height is increased, the patterns become shorter and wider--eventually becoming round. Predicted maximum contour area lengths are given in table 6. Figure 19 shows actual 700-gallon, 1,400-gallon, and sequential drop patterns.

Inspection of the data on contour area lengths for the sequential or trail drops performed revealed, first, that pilot control of sequential timing is inconsistent and cannot be relied upon. Times between gate openings varied between 0.17 and 1.75 seconds, indicating that an adjustable intervalometer is necessary to achieve consistency and pattern uniformity. Second, the use of sequential drops can greatly increase line lengths as compared to a single 700- or 1,400-gallon drop (fig. 19). The limited accuracy with which a pilot can hit a target, and his inability to identify the effective portion of the pattern, limit the maximum length of line that can be obtained by sequential drops. According to the data in table 6, the longest continuous patterns were attained when the interval time was approximately 1.0 second. A properly set intervalometer incorporated into the gating system improves accuracy by eliminating the need for a second separate drop.

Drop number	5	16	3
Drop size (gal)	700	1400	1400
Mode	Salvo	Salvo	Sequential
Height (ft)	148	128	110
Groundspeed (knots)	109	103	105

Drop patterns (0.2, 1.0, 2.0, AND 4.0 GAL/100 FT^2 CONTOURS)



≥ 2 gal/100 ft^2 contour			
Number of segments	1	1	2
Length (ft)	207	254	499

Figure 19.--Effect of load size and drop mode on ground distribution patterns.

Other Drop Responses

In addition to the ground distribution patterns, several related drop responses are important in evaluating an aircraft tank and gating system and the drop characteristics of the different retardants. The ground distribution patterns are affected by the time required for the retardant to leave the aircraft (exit time or retardant flow rate), the trajectory of the retardant (aircraft attitude), and the time required for the retardant to reach the ground (evaporation losses). Each of these variables is affected by the retardant rheological properties,[4/] which partially determine the rate of stripping of the retardant mass, the size and distribution of the droplets formed during the erosion process, and thus the total surface area of the droplets.

The importance of these parameters can be assessed by an analysis of exit times, drop trajectories, drop times, and evaporation losses for drops of each retardant.

Retardant Exit Time

The exit time for each retardant (Appendix I, tables 14-17) was studied as a function of load size; previous studies had indicated that drop speed, windspeed, and wind direction did not significantly affect exit times (George and Blakely 1973). It was anticipated that increasing load size would not cause an increase in exit time from the CL-215, because a 1,400-gallon drop is simply two 700-gallon drops released simultaneously. The mean exit times for both load sizes and all retardants were calculated, and a "t" test was used to determine the significance of differences in mean exit times for the two load sizes. The results (table 7) indicate that 700- and 1,400-gallon load sizes differed at the 95 percent significance level for only water and Gelgard. It is doubtful, though, that these differences are meaningful because the magnitude of the differences is small: 0.17 and 0.10 second for Gelgard and water, respectively.

Differences between mean exit times for each retardant and at each load size were also tested using a "t" test. Although the differences between retardants were small, they were significant. The difference between the uncolored retardants (Gelgard and water) and the colored retardants (Phos-Chek XA and Fire-Trol 100) was significant at a level greater than 98 percent. Because the exit times were determined from 70-mm or 16-mm movie film, the beginning and ending times are dependent upon visibility and thus color intensity. Therefore, it is reasonable to assume some of the differences between the colored and uncolored products could be due to judgment by those examining the film. This may explain why for some drops, exit times for the larger load sizes and highly viscous retardants (Phos-Chek XA and Fire-Trol 100) are not longer than those for the low viscosity retardants (Gelgard and water) as might be expected. In any event, the difference in exit times caused by load size and type of retardant is small (approximately 0 to 0.20 s) and probably not meaningful when related to the effect of other parameters.

[4/] Rheology is the science of the deformation and flow of material. It is primarily concerned with deformation of *cohesive* bodies and their stress-strain-time relationship. Here, cohesion relates to the sticking together of particles or drops to maintain a homogeneous mass. Rheologic properties should be differentiated from viscous properties. The viscosity of a retardant solution, as normally measured at a single rate of shear, is only one rheological parameter and does not necessarily define the cohesiveness of the material.

TABLE 7.--SIGNIFICANCE BY "T" TEST OF DIFFERENCES IN EXIT TIMES FOR 700- AND 1,400-GALLON DROPS OF FOUR RETARDANTS

Retardant	Load size	Number of drops	Mean exit time	Value of t	Degrees of freedom	Significance level[1]
	Gallons		*Seconds*			*Percent*
Phos-Chek XA	700	5	1.87	1.48	14	NS
	1,400	10	1.98			
Gelgard	700	4	1.65	3.05	7	98
	1,400	5	1.82			
Fire-Trol 100	700	4	1.96	.73	8	NS
	1,400	6	2.00			
Water	700	7	1.92	2.17	10	95
	1,400	5	1.82			
All retardants pooled	700	21	1.86	1.47	--	NS
	1,400	26	1.92			
All retardants pooled	All sizes pooled	47	1.89			

1/ NS = no significant difference (level of significance <0.90).

Drop Time and Trajectory

Under similar drop conditions (aircraft speed, drop height, windspeed and direction, aircraft attitude, etc.) the time required for a retardant to reach the ground is a function of the stripping and erosion process primarily determined by the retardant's rheological properties. Theoretically, an analysis of drop times for each of the retardants (Appendix I, tables 14-17) should support the earlier results showing that gum-thickened retardants produce larger droplet sizes with less erosion and drift (under similar conditions) and thus more concentrated patterns. Thus, drop times for the gum-thickened retardants should be shorter than for those retardants producing smaller droplet sizes.

Covariance analysis indicated that load size and type of aircraft, in addition to drop height, were the primary variables governing the drop time. The other variables may also affect drop time but because some of these variables were held constant as far as possible, and because of substantial variation within the data, they had insignificant effects. Testing the pooled versus unpooled models for load size for each retardant revealed significant differences at the ≥95 percent level for each retardant. These differences in drop times with load size were generally small (<1 s) and as in the analysis of exit times, are probably not meaningful. Larger differences with load size in the stripping and erosion of a retardant might be expected if a 1,400-gallon drop acted as a single entity rather than as two 700-gallon increments. (A larger single mass would require a greater distance and longer time for complete erosion or stripping to occur.)

An analysis of drop time similar to that for load size was undertaken for type of retardant. In all combinations, except when Phos-Chek XA and Gelgard were pooled, significant differences in drop times at the 99 percent level did occur. Drop times for

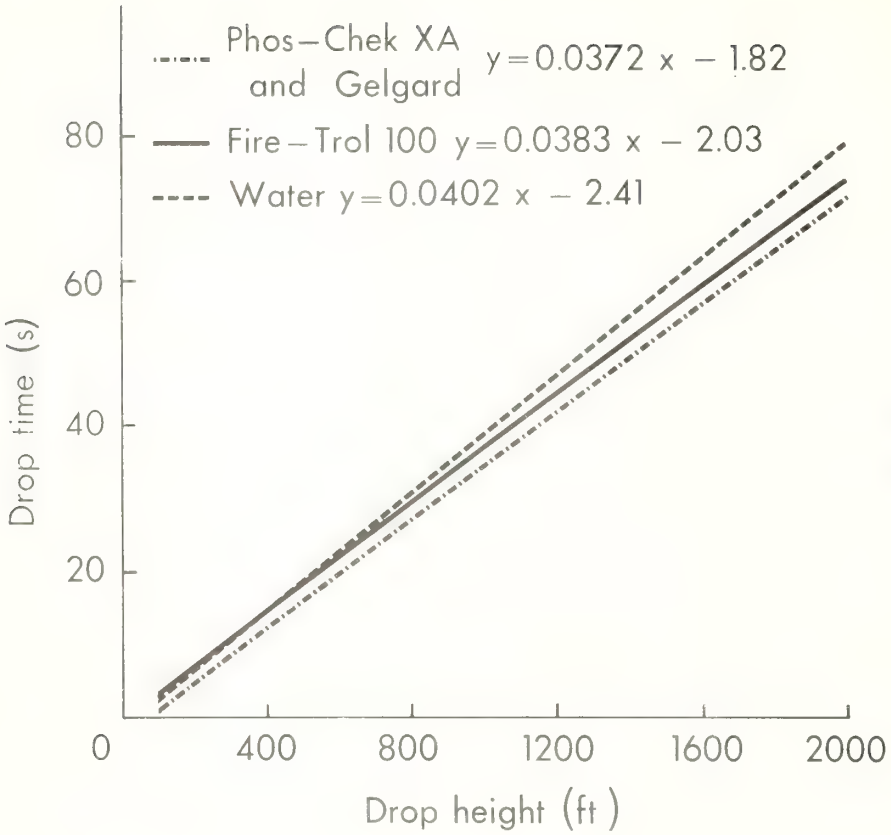


Figure 20.--Time required for the retardants to reach the ground as a function of drop height.

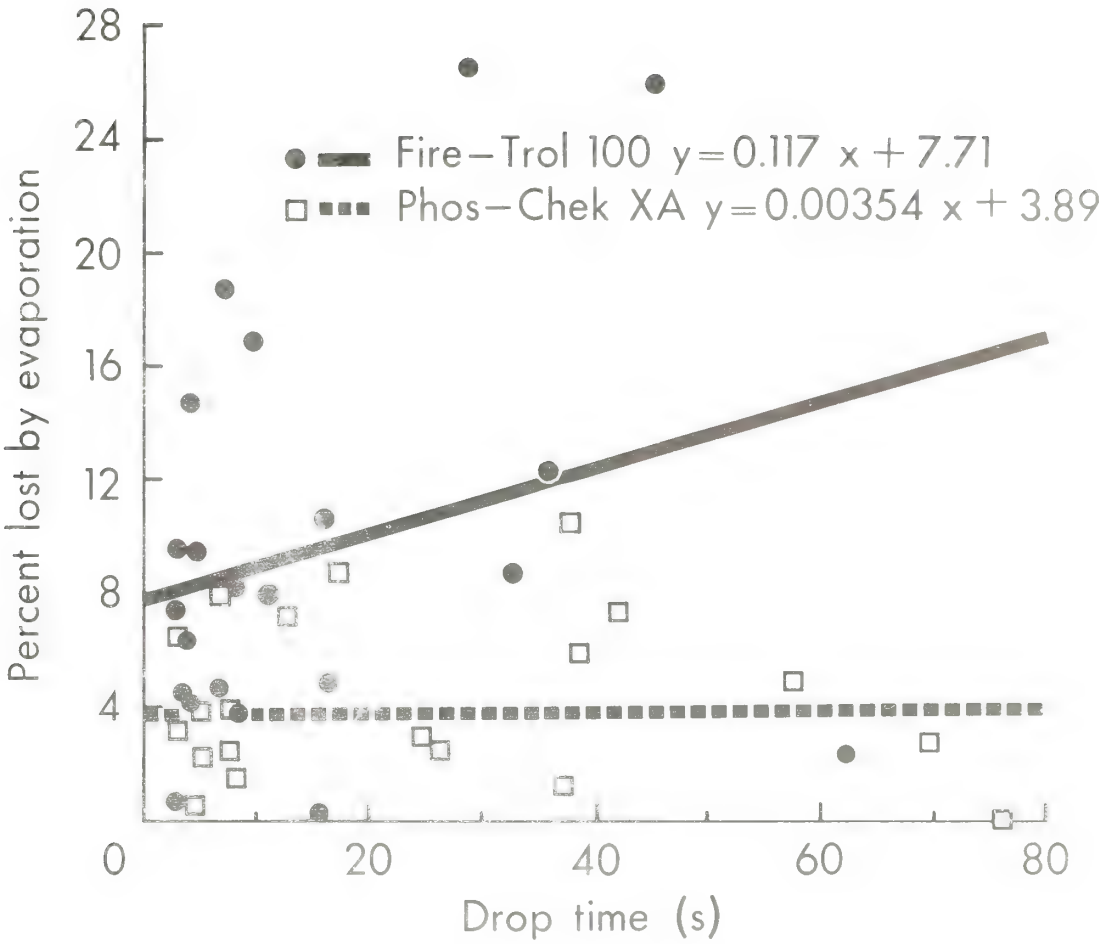
Phos-Chek XA and Gelgard were not significantly different although they had the shortest drop time for the retardants tested. Fire-Trol 100 required approximately one additional second and water required 2 to 3 additional seconds to reach the ground (depending on the drop height used for comparison). The regression equations are given and the difference between retardants is shown graphically for the retardants (load sizes pooled) in figure 20.

A "t" test was used to evaluate the difference in horizontal and vertical trajectories for the different load sizes and retardants. Inspection of the summary of these results indicated no general trend and results were inconsistent as to trajectories and load sizes. It is likely that the large amount of within-data variation caused by the many affecting variables limits the usefulness of other than average trajectory values for comparison. These values may, however, provide clues to a better understanding of the stripping and erosion processes taking place during a drop.

Quantification of the effect of increased airspeed on drop trajectory was considered impossible because of variation within the data, the limited number of drops of each retardant in the high-speed mode, and our indefinite results in analyses of drop trajectories in the normal-speed mode.

Evaporation Losses

The evaporation occurring during a drop under given environmental conditions is primarily a function of the degree of erosion and history of the drop mass; that is, droplet size and distribution and the fall history of the droplets, and thus the



relation between droplet surface area and atmosphere exposure. When evaporation losses have been determined, retardant loss from drift can be calculated as the remainder not accounted for in the ground distribution pattern.

The percent of the load lost to evaporation[5/] for the two retardants con[illegible] (Phos-Chek XA and Fire-Trol 100) was plotted as a function of the drop time, [illegible] previously been correlated to drop height. Covariance analysis suggested that [illegible] differences between the 700- and 1,400-gallon load size existed for either re[illegible]. As expected on the basis of differences in drop times, real differences were [illegible] between Phos-Chek XA and Fire-Trol 100, with less evaporation loss occurring [illegible] Phos-Chek XA drops in all case[illegible] losses for Fire-Trol 100 of between 6 and 15 percent; whereas, losses for Phos-Chek XA fall between 3 and 5 percent, depending on the drop time. For both retardants, [illegible]ing evaporative losses occurred as drop time increased.

5/The evaporation of water during a drop was calculated from the difference in retardant salt content before and after the drop (see earlier discussion of measurement of retardant properties).

DISCUSSION

The objectives of the study were to determine the effects of drop height and load size on ground distribution patterns of several retardants and provide performance data on the tank and gating system of the CL-215. These objectives were achieved by quantification and analysis of the amount of retardant reaching the ground and the distribution of this retardant, including the length of contour areas (fireline) at the various concentrations as affected by retardant type, load size, drop height and speed, aircraft attitude, and drop conditions.

Drop height and load size were found to be the most significant variables, affecting almost all measured parameters for the retardants dropped. Covariance analysis of the linear drop height models for total recovery indicated significant differences existed between all retardants except Fire-Trol 100 and water; i.e., Phos-Chek XA had the greatest recovery, followed by Gelgard, and then Fire-Trol 100 and water.

Because, in most instances, real differences between retardants appeared to exist in the simple linear models for total retardant recovered, three-dimensional models of the drop height-retardant concentration (distribution) interactions were developed; and because the total retardant values do not describe the actual distribution, similar three-dimensional models for area of coverage and contour area length were developed. In combination, these models describe the ground distribution patterns. In general, the models show that recoveries, areas of high concentrations ($\geq$2 gal/100 ft^2), and contour area lengths were largest for Phos-Chek XA, with Gelgard, Fire-Trol 100, and water following in that order. Predictions were made from these models for each parameter, retardant, and load size (Appendix I, tables 14-17).

The models and predictions for the gum-thickened retardants (Phos-Chek XA and Gelgard) indicate that as load size is increased, the optimum drop height for any required concentration is also increased. For example, the drop height producing the maximum coverage at a concentration of $\geq$2 gal/100 ft^2 for a 700-gallon Phos-Chek XA drop is about 268 feet. The height for maximum coverage at this concentration level for a 1,400-gallon drop is about 806 feet. Thus, if the load size is doubled, the optimum drop height is tripled, and the actual area covered at the optimum height is more than doubled (8,944 ft^2 for a 700-gallon drop compared to 23,413 ft^2 for a 1,400-gallon drop). For comparison, the drop height producing the optimum coverage for Fire-Trol 100 and water drops at this concentration level is near 150 feet.

The data analysis indicates that the optimum drop height for Fire-Trol 100 and water for attaining maximum recovery, areas of coverage, and line lengths at a concentration level of $\geq$2 gal/100 ft^2 is near 150 feet. The optimum height for Phos-Chek XA and Gelgard can be as much as two to five times higher. Thus, effective drop heights and safety may be greatly increased by the use of gum-thickened retardants such as Phos-Chek XA and Gelgard. Also, comparison of the drop characteristics of Fire-Trol 100 and water indicates that little value is obtained by adding the clay thickeners to retardant solutions. Although increasing load size improves drop characteristics, the effect is not fully gained with the CL-215 because a 1,400-gallon drop is actually achieved by simultaneously opening two 700-gallon tanks separated by several feet. Thus, if progress is to be made in attaining higher effective drop heights, so as to develop the capability of a safe night retardant cascade delivery method for larger aircraft, the use of gum-thickened retardants offers the most promise.

The effects of increased aircraft drop speed on ground distribution patterns were studied. The effect of a 20-knot increase in speed (105 to 125 knots) was small or fell within experimental variation in the data. Visual inspection of the data indicated that greatest effect of airspeed was on contour area lengths at concentration levels of 0.2 and 0.5 gal/100 ft^2. These lengths tended to increase with the higher drop speeds. At concentrations of ≥2 gal/100 ft^2, contour area lengths decreased with the increased drop speed. The effect of aircraft attitude was also investigated by making drops from a level, bank, loft, and dive mode. In all drops, the ground pattern responses for the bank, loft, and dive mode fell within the responses attained for the level mode.

The average time required for the retardant to leave the CL-215 was 1.89 seconds, which is within the range of exit times for other presently used air tankers. The effect of load size on retardant exit times was found to be statistically significant for water and Gelgard, but not for Phos-Chek XA and Fire-Trol 100. It is doubtful that any of the differences are meaningful, as they are small (<0.20 s) and the variation within the data is comparatively large.

The drop times and evaporation losses were analyzed and support the conclusions made from ground distribution patterns. The drop times were shortest for Phos-Chek XA and Gelgard, followed by Fire-Trol 100 and water, in that order. Smaller drop times for a given retardant indicate greater cohesion in the drop, a longer stripping time, and a larger mean droplet size after erosion. Evaporation losses depend primarily on the amount of surface area exposed, and thus should be greater for droplets of smaller mean diameter. Significantly less evaporation occurred with Phos-Chek XA (3 to 5 percent lost) than with Fire-Trol 100 (6 to 15 percent lost). Evaporation losses for Gelgard and water could not be measured since they do not contain the salt which provided the basis for analysis.

Variation within the vertical and horizontal trajectory data, partially caused by the measuring techniques used, made it impossible to determine and quantify differences for the retardants. It was observed, however, that the mean horizontal and vertical trajectories for 600-gallon drops made from the TBM aircraft, as quantified in the Porterville study (George and Blakely 1973) were 487 and 84 feet, respectively; whereas, trajectories for the CL-215 (700- and 1,400-gallon loads performed similarly) were 544 and 160 feet. The increase in vertical trajectory for the CL-215 is most likely due to tank geometry and load size (the CL-215 has 56.5 gal/ft^2 of gate opening while the TBM has 35.0 gal/ft^2 of gate opening). The conclusion is that minimum drop heights should be raised for safety of aircraft having larger tank capacities or of tank and gating systems producing fast exit times and high volume flow rates.

Evaluation of the tank and gating system of the CL-215 and comparison of its performance with that of other presently used aircraft are complicated by the large number of variables affecting both the delivery system performance and the actual ground distribution requirements. A simple comparison of the lengths of contour areas at the ≥2 gal/100 ft^2 concentration level for the CL-215 tank and gating system and several presently used aircraft reveals no unusually large differences in performance (table 8 and fig. 22). A comparison of line building efficiencies (feet of adequate concentration or ≥2 gal/100 ft^2 line per gallon carried) shows the CL-215 to be as effective as other presently used air tankers; it provides 0.38 foot of fireline per gallon at 150-foot drop heights and 0.32 foot of fireline per gallon at 300-foot drop heights. The CL-215 does have the disadvantage of a low load capacity (1,400 gallons) as evident from the relatively large number of trips required per mile of line built (table 8). The performance and flexibility of the CL-215 tank and gating system could be improved if a four-tank or gate system incorporating an intervalometer were adopted rather than a manually sequenced two-gate system.

TABLE 8.--LINE BUILDING CAPABILITIES OF THE CL-215 AND SEVERAL OTHER AIR TANKERS WITH PLOS-OVER NA[1/]

Aircraft	Capacity	Maximum number of drop increments possible[2/]	Drop height of 150 feet: Maximum length of adequate fireline[3/]	Drop height of 150 feet: Foot of line per gallon carried	Drop height of 150 feet: Trips per mile of line[4/]	Drop height of 300 feet: Maximum length of adequate fireline[3/]	Drop height of 300 feet: Foot of line per gallon carried	Drop height of 300 feet: Trips per mile of line
	Gallons							
CL-215	1,400	2	534	0.38	9.9	444	0.32	11.9
TBM (TBM, Inc.-60)	600	2	235	.39	22.5	186	.31	28.4
B-17-AU (Aero Union-17)	2,000	2	688	.34	7.7	456	.23	11.6
B-17-INT. (Intermountain-71)	2,000	4	908	.45	5.8	632	.32	8.4
PB4Y2 (Stell C-50)	2,400	8	904	.38	5.8	816	.34	6.5
C-119 (Aero Union-12)	2,400	4	904	.38	5.8	560	.23	9.4
P2V (USFS)	3,000	6	948	.32	5.7	876	.29	6.0
DC-6B (Gilbertson)	3,000	8	960	.32	5.5	784	.26	6.7
C-130 (MAFFS) (Air Force-FMC)	3,000	[5/]1	1,800	.60	2.9	1,200	.40	4.4

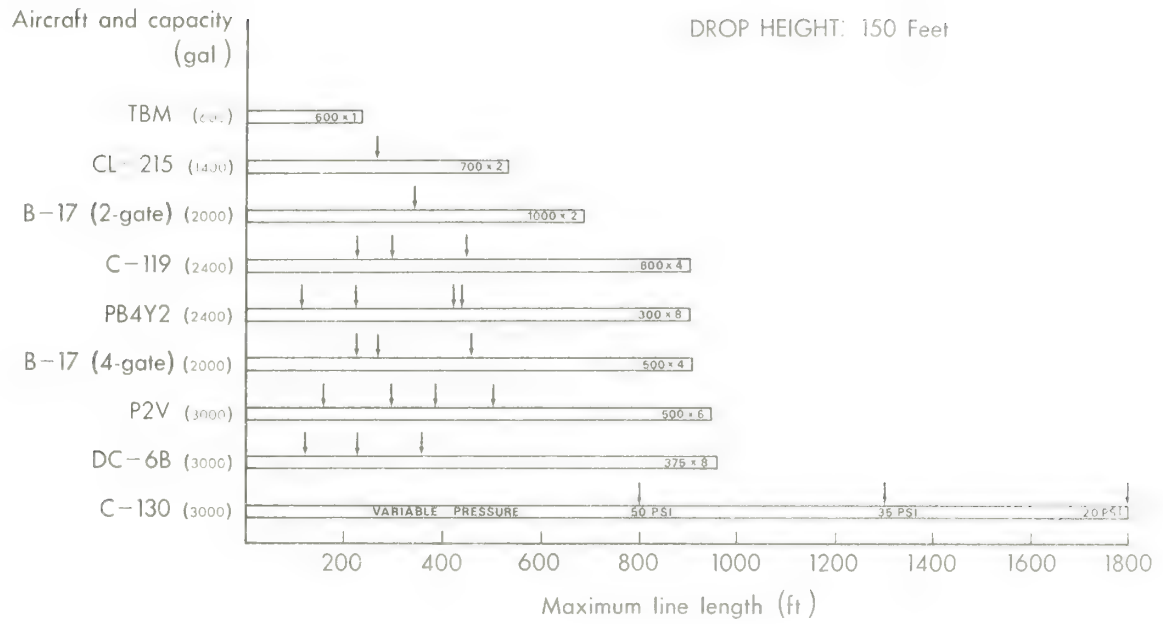
[1/] Data from George and Blakely (1973), USDA Forest Service (1973), and Marana Drop Test data on file at Northern Forest Fire Laboratory, Missoula, Montana.

[2/] Does not consider special gating systems such as the gravity flow trail gates provided on the Aero Union B-17 and C-119. The number of increments is usually equal to the number of gates.

[3/] Adequate retardant concentration was defined for this comparison as ≥ 2 gal/100 ft^2.

[4/] Trips required to build 1 mile of fireline were chosen for comparison; this length of line would surround a 40-acre fire.

[5/] Pattern flexibility is achieved through variable pressures producing flow rates up to 30,000 gal/min.



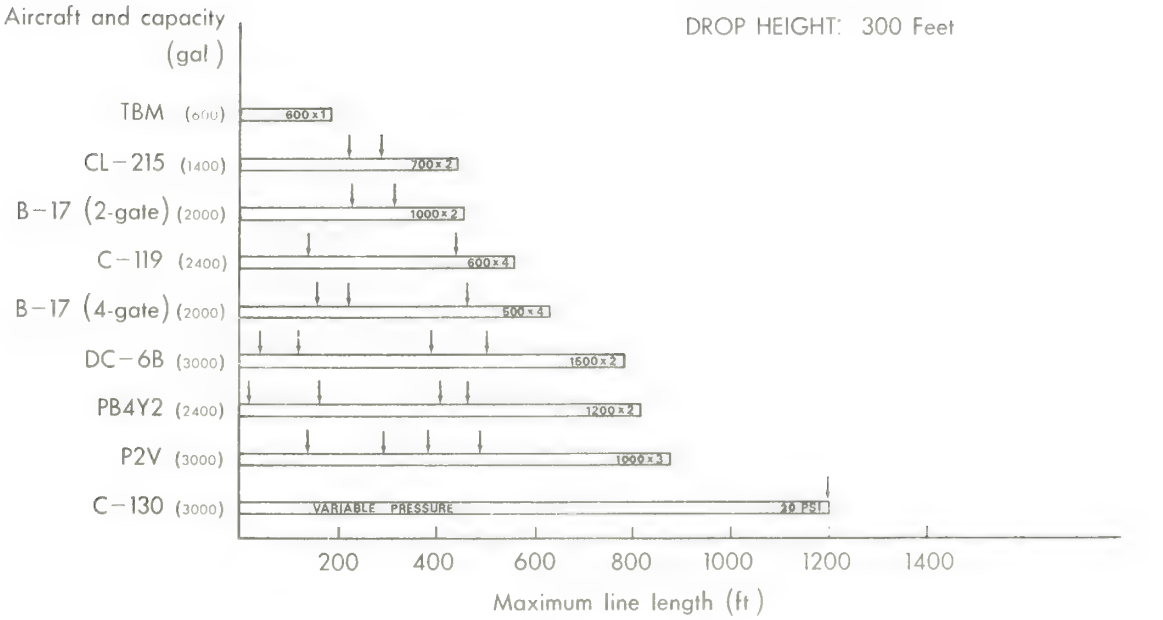


Figure 22.--The length of fireline capable of being built by several comparable airplanes at a drop height of 150 and 300 feet. The flexibility of various tank and gating systems (not including trail gate systems) is shown by the small arrows as possible fireline lengths using different gate combinations.

LITERATURE CITED

George, Charles W.
1971a. Liquids fight forest fires. Fert. Solutions 15(6):10-11, 15, 18, and 21, illus.

George, Charles W.
1971b. Retardant salt concentration measured in the field. USDA For. Serv. Res. Note INT-138, 14 p.

George, Charles W., and Aylmer D. Blakely
1972. Effects of ammonium sulfate and ammonium phosphate on flammability. USDA For. Serv. Res. Pap. INT-121, 26 p., illus.

George, Charles W., and Aylmer D. Blakely
1973. An evaluation of the drop characteristics and ground distribution patterns of forest fire retardants. USDA For. Serv. Res. Pap. INT-134, 60 p., illus.

George, Charles W., and Charles E. Hardy
1966. Fire retardant viscosity measured by modified Marsh funnel. U.S. For. Serv. Res. Note INT-41, 4 p., illus.

Jensen, Chester E., and Jack W. Homeyer
1970. Matchacurve-1 for algebraic transforms to describe sigmoid- or bell-shaped curves. USDA For. Serv., Intermt. For. & Range Exp. Stn., 22 p., illus.

Jensen, Chester E., and Jack W. Homeyer
1971. Matchacurve-2 for algebraic transforms to describe curves of the class X^n. USDA For. Serv. Res. Pap. INT-106, 39 p., illus.

MacPherson, J. I.
1967. Ground distribution contour measurements for five firebombers currently used in Canada. Nat. Res. Counc. Can., Aeron. Rep. LR-493, 66 p., illus.

National Fire Protection Association
1967. Chemicals for forest fire fighting. Ed. 2, 112 p., illus. National Fire Protection Association, Boston.

USDA Forest Service
1969. Specification for retardant, forest fire, dry chemical for fixed-wing aircraft application. USDA For. Serv. Interim Specif. 5100-00301, 20 p., illus.

USDA Forest Service
1973. The CL-215: summary of its performance as an air tanker. 57 p., illus. Wash., D.C.

APPENDIX I

Tables 9-44

TABLE 9.--COMPOSITION OF THE FIRE RETARDANTS EVALUATED[1/]

	Composition	Approximate percent in dry product or concentrate
	LONG-TERM RETARDANTS	
Phos-Check YA	Diammonium phosphate $(NH_4)_2HPO_4$ (21-53-0)	89
	Guar gum (thickening agent)	8
	Iron oxide (coloring agent)	1
	Corrosion and spoilage inhibitors	2
Fire-Trol 100	Ammonium sulfate $(NH_4)_2SO_4$ (21-0-0)	62
	Attapulgite clay (thickening agent)	36
	Iron oxide (coloring agent)	1
	Corrosion inhibitor	1
	SHORT-TERM RETARDANT	
Gelgard[2/]	Synthetic organic polymer	99
	Carmine 2B dye	<1

[1/] From George 1971a.

[2/] The standard Gelgard polymer (Gelgard M) is colorless. Gelgard containing a pigment (Gelgard F) can be obtained or dye can be added.

TABLE 10.--RETARDANT CHARACTERISTICS BEFORE AND AFTER EACH TEST DROP OF PHOS-CHEK XA

Drop No.	Characteristics before drop: Viscosity	Density	Salt content	Characteristics after drop: Density	Salt content	Increase in salt content	Water loss during drop 1/	
	Centipoise	G/cc	Percent $(NH_4)_2HPO_4$	G/cc	Percent $(NH_4)_2HPO_4$	Percent	Gallons	Percent
3	1,600	1.088	13.21	1.089	13.26	0.4	6.6	0.5
4	2,400	1.094	13.81	1.096	14.04	1.7	12.7	1.8
5	1,550	1.074	10.98	1.081	11.73	6.8	49.0	7.0
16	1,590	1.067	10.11	1.068	10.19	.8	12.3	.9
17	1,650	1.069	10.35	1.072	10.77	4.1	29.1	4.2
21	1,390	1.064	9.85	1.071	10.69	8.5	118.4	8.5
35	1,690	1.068	10.40	1.074	10.97	5.5	80.2	5.7
36	1,960	1.077	11.53	1.082	12.05	4.5	33.3	4.8
37	2,175	1.077	11.36	1.077	11.46	1.0	6.1	1.0
38	1,700	1.071	10.44	1.078	11.62	11.3	150.3	10.7
45	1,800	1.070	10.50	1.071	10.63	1.2	8.6	1.2
46	2,050	1.069	10.56	1.080	11.79	11.6	158.8	11.3
50	1,560	1.064	9.49	1.071	10.24	7.9	110.0	7.9
51	1,200	1.065	9.81	1.067	9.85	.4	4.1	.6
52	1,775	1.071	10.42	1.074	10.86	4.2	60.5	4.3
53	2,950	1.093	13.80	1.096	14.17	2.7	20.1	2.9
54	1,850	1.076	11.28	1.081	11.99	6.3	89.0	6.4
57	1,600	1.070	10.46	1.088	13.19	26.1	308.1	22.0
64	1,600	1.072	10.73	1.071	10.99	2.4	31.8	2.3
65	1,960	1.078	11.75	1.080	12.10	3.0	43.0	3.1
66	1,500	1.067	10.13	1.070	10.67	5.3	74.6	5.3
73	1,550	1.067	10.34	1.073	10.57	2.2	19.1	2.7
79	1,940	1.073	10.99	1.075	11.05	.5	5.1	.7
80	1,760	1.068	10.22	1.071	10.56	3.3	24.4	3.5
81	1,410	1.068	10.28	1.074	10.58	2.9	47.3	3.4
Mean	1,767	1.073	10.91	1.077	11.44	5.1	53.7	5.0

1/ The water loss during the drop is calculated from the increase in the salt content of the retardant reaching the ground. Percent values shown represent percent loss based on the drop size.

TABLE 11.--RETARDANT CHARACTERISTICS BEFORE AND AFTER EACH TEST DROP OF GELGARD

Drop No.	Characteristics before drop: Viscosity	Density	Characteristics after drop: Viscosity
	Centipoise	G/cc	Centipoise
7	1,500	--	--
8	1,100	--	--
9	--	--	1,410
11	850L/800R	0.999	875
12	850	.994	925
13	900	.999	875
14	650	1.003	925
15	875L/800R	1.000	1,050
74	900	--	--
75	600	--	--
76	600	--	--

TABLE 12.--RETARDANT CHARACTERISTICS BEFORE AND AFTER EACH TEST DROP OF FIRE-TROL 100

Drop No.	Characteristics before drop			Characteristics after drop		Increase in salt content	Water loss during drop 1/	
	Viscosity	Density	Salt content	Density	Salt content			
		g/cc	Percent $(NH_4)_2SO_4$	g/cc	Percent $(NH_4)_2SO_4$	Percent	Gallons	Percent
18	1,950	1.141	14.71	1.141	15.31	4.1	27.4	3.9
19	2,300	1.146	15.26	1.159	16.86	10.5	73.5	10.5
25	2,380	1.142	15.55	1.148	16.11	5.0	73.0	5.2
26	1,700	1.136	15.20	1.152	15.98	5.1	86.8	6.2
27	2,280	1.129	14.99	1.171	18.34	22.3	296.7	21.2
28	1,950	1.115	15.40	1.155	15.44	.03	12.9	1.8
34	2,140	1.122	15.69	1.134	14.29	4.4	73.0	5.2
40	2,275	1.128	14.17	1.158	17.45	23.1	146.3	20.9
41	2,160	1.139	15.36	1.150	16.41	6.8	102.1	7.3
42	2,240	1.132	14.87	1.149	16.81	13.0	180.0	12.9
43	2,350	1.143	15.26	1.163	16.71	9.5	145.5	10.2
47	1,750	1.135	15.16	1.161	16.96	11.9	85.3	12.6
48	2,600	1.144	15.24	1.173	17.54	15.8	100.0	14.3
59	2,200	1.154	15.21	1.168	18.31	20.4	270.9	19.3
60	1,910	1.145	16.12	1.155	19.85	23.0	249.2	21.3
61	2,375	1.147	16.20	1.179	19.00	17.5	119.4	17.1
62	2,300	1.140	16.11	1.162	16.70	3.7	65.6	4.5
67	2,250	1.136	14.73	1.148	16.01	8.7	126.5	9.9
68	2,250	1.140		No sample				
69	2,250	1.141	14.82	1.161	16.08	8.5	151.4	8.4
70	2,075	1.136	15.05	1.154	16.65	10.6	99.1	11.0
71	2,200	1.132	14.84	1.154	17.65	18.9	97.7	21.0
72	2,000	1.141	15.46	1.174	18.69	20.9	78.1	25.5
77	2,800	1.145	15.57	1.270	20.71	33.0	410.8	28.5
78	2,350	1.144	15.25	1.245	20.74	36.0	211.5	36.2
Mean	2,162	1.137	15.16	1.162	17.49	12.9	126.7	12.1

1/ The water loss during the drop is calculated from the change in the salt content of the retardant remaining on the ground. Percent values above represent percent lost based on the drop size.

TABLE 13.--ENVIRONMENTAL CONDITIONS DURING EACH TEST DROP OF WATER AND CHEMICAL RETARDANTS

Drop No.	Air temperature	Relative humidity	Windspeed	Wind direction[1]	Drop No.	Air temperature	Relative humidity	Windspeed	Wind direction[1]
	°F	Percent	M/h	Degrees		°F	Percent	M/h	Degrees
		PHOS-CHEK XA					GELGARD		
3	61	36	4.5	135 L	7	65	30	3.2	28 R
4	68	28	7.4	60 R	8	74	22	4.7	12 L
5	68	28	12.2	107 R	9	77	19	4.0	68 L
16	54	45	5.3	118 L	11	58	41	8.7	96 L
17	59	42	7.3	152 L	12	64	35	8.9	122 L
21	50	54	9.8	125 L	13	73	26	5.4	127 R
35	68	30	5.4	30 R	14	72	25	5.4	130 R
36	68	30	4.8	90 R	15	71	25	6.7	54 R
37	53	53	6.0	132 L	74	56	41	1.8	110 R
38	58	46	6.7	129 L	75	64	32	5.8	10 R
45	70	27	2.2	160 L	76	65	30	3.8	90 R
46	70	26	1.7	72 R					
50	68	28	6.1	56 R					
51	69	27	6.7	105 R			[2]WATER		
52	58	40	8.4	129 L					
53	57	58	9.3	123 L	1	69	22	5.3	63 R
54	63	33	6.4	170 L	2	68	22	5.6	67 R
57	78	20	2.8	95 R	6	63	34	2.0	61 R
64	69	35	5.4	170 R	10	75	18	4.2	110 L
65	50	66	5.4	90 L	20	71	25	5.0	57 R
66	53	55	4.8	22 L	23	58	44	8.3	143 L
73	64	28	3.7	55 R	24	63	40	8.0	132 L
79	52	43	4.8	104 L	29	69	26	6.2	62 R
80	62	32	2.5	100 R	30	68	27	7.1	68 R
81	64	29	2.8	31 R	31	66	28	5.3	32 R
					32	52	55	6.8	110 L
					33	56	50	7.2	138 L
		FIRE-TROL 100			39	68	29	2.3	179 R
					44	65	35	4.7	82 L
18	69	30	1.7	129 R	49	68	28	6.2	32 R
19	70	28	1.7	11 R	55	66	30	7.2	102 L
25	65	35	7.4	113 L	56	71	28	5.8	112 L
26	69	32	3.2	112 L	58	81	20	6.5	158 R
27	72	24	5.7	90 R	67	57	44	8.7	88 R
28	69	26	8.2	93 R	82	65	23	6.4	90 R
34	69	32	1.8	90 L	83	66	20	8.3	92 R
40	69	28	2.1	52 L					
41	68	28	7.3	51 R					
42	55	48	3.0	138 L					
43	62	36	5.3	80 L					
47	54	48	6.7	116 R					
48	62	36	--	75 R					
59	75	22	10.1	85 R					
60	75	22	9.8	76 R					
61	74	21	8.3	60 R					
62	69	36	9.6	170 R					
63	69	35	7.5	170 R					
68	59	43	4.8	82 R					
69	62	42	9.2	98 R					
70	62	38	4.2	45 R					
71	62	34	8.1	74 R					
72	63	30	4.3	75 R					
77	67	28	7.2	65 R					
78	67	26	5.5	92 R					

[1] Degrees left or right of grid center (0° = tailwind, 180° = headwind).

[2] At a viscosity of 1.0 centipoise and a density of 1.0 g/cc.

TABLE 14.--AIRCRAFT HEIGHT AND SPEED, AND DROP HISTORY AND TRAJECTORY FOR [illegible]

Drop No.	Load size and drop mode[1/]	Drop speed	Drop height	Drop history[2/] Time to exit tank	Time to reach ground	Time to settle	Drop trajectory Horizontal	Vertical
		Knots	[illegible]	- - - - - -	Seconds	- - - - - -	Feet	- - - - -
3	1,400(T)	105	110	3.67	2.81	10.58	--	--
4	700	107	315	1.94	8.21	--	534	205
5	700	109	148	2.10	3.19	8.92	--	--
16	1,400	103	128	1.90	2.88	10.33	--	--
17	700	97	311	1.79	8.17	--	526	205
21	1,400	92	296	1.94	6.94	13.04	--	--
35	1,400(T)	104	208	2.67	5.15	13.48	--	--
36	700	103	350	1.98	17.17	--	574	213
37	700(HS)	112	366	1.94	10.67	--	616	214
38	1,400	102	486	1.98	13.71	22.98	576	304
45	700	107	1,046	1.69	--	--	550	221
46	1,400	104	1,007	--	--	--	--	--
50	1,400	105	--	1.98	--	--	524	267
51	700(HS)	120	177	1.63	4.50	12.83	--	--
52	1,400	99	316	2.13	7.67	15.88	512	238
53	700	97	738	1.73	--	--	--	--
54	1,400	89	1,101	2.17	--	--	--	--
57	1,400	--	--	1.77	--	--	533	204
64	1,400	91	317	2.06	8.77	16.44	--	--
65	1,400	94	--	1.92	--	--	--	--
66	1,400	107	--	--	--	--	--	--
73	700(D)	116	183	1.54	5.33	12.71	--	--
79	700(B)	99	163	1.83	4.56	11.60	492	188
80	700(L)	123	201	1.40	3.06	9.79	--	--
81	1,400	95	--	1.90	--	--	--	--
Mean							544	226

1/ The aircraft drop mode is given by the letter in parentheses: T = 700 gallons × two trail drops, B = bank attitude, D = dive attitude, L = loft attitude, HS = high speed drop (approximately 12[illegible] knots). All others were salvo drops made with the aircraft in a horizontal attitude at a normal drop speed (approximately 105 knots).

2/ Available data depended on movie film coverage. Where data are lacking, the drop release or empty point was out of the camera's view.

TABLE 15.--AIRCRAFT HEIGHT AND SPEED, AND DROP HISTORY AND TRAJECTORY FOR GELGARD

Drop No.	Load size and drop mode[1/]	Drop speed	Drop height	Drop history[2/] Time to exit tank	Time to reach ground	Time to settle	Drop trajectory Horizontal	Vertical
	[illegible]	[illegible]	[illegible]	- - - - - -	[illegible]			
7	700	120	147	1.60	3.94	11.00		
8	700	106	974	--	29.71			
9	700	109	463	1.69	13.[illegible]	28.46		
11	1,400	99	164	1.75	7.88	11.91		
12	700	96	301	1.56	8.90	[illegible]	1[illegible]	183
13	1,400	96	982	1.79				
14	1,400	102	4[illegible]	1.92	13.46		550	[illegible]
15	1,400	104	310	1.77	7.[illegible]			
74	700	--	[illegible]	1.75				
75	700(HS)	130	250	1.73	7.[illegible]	20.17		
76	1,400	91	505	1.88	14.83	31.06	[illegible]	245
Mean								231

1/ The aircraft drop mode is given by the letter in parentheses: [illegible] 125 knots). All others were salvo drops made with the aircraft in a horizontal attitude at a normal drop speed (approximately 105 knots).

2/ Available data depended on movie film coverage. Where data are lacking, the drop release or empty point was out of the camera's view.

TABLE 16.--AIRCRAFT HEIGHT AND SPEED, AND DROP HISTORY AND TRAJECTORY FOR FIRE-TROL 100

Drop No.	Load size and drop mode[1/]	Drop speed	Drop height	Drop history[2/] Time to exit tank	Time to reach ground	Time to settle	Drop trajectory Horizontal	Drop trajectory Vertical
	Gallons	*Knots*	*Feet*	*Seconds*			*Feet*	
18	700	105	296	1.85	8.13	18.15	554	210
19	700	106	164	1.94	4.58	14.81	566	163
25	1,400	105	272	1.85	6.69	20.83	--	--
26	1,400	104	494	2.00	16.40	--	549	242
27	1,400	103	952	--	--	--	--	--
28	700	104	482	1.98	15.67	29.97	529	242
34	1,400(T)	105	183	-	4.04	19.48	--	--
40	700	100	1,043	--	--	--	--	--
41	1,400	94	157	2.13	3.92	13.40	--	--
42	1,400(HS)	118	294	2.13	8.19	21.25	589	258
43	1,400	109	981	2.10	--	--	--	--
47	1,400(T)	125	294	1.92	10.60	27.08	584	181
49	1,400(HS)	123	299	2.04	9.58	23.44	679	188
60	700(HS)	121	214	2.06	7.19	18.90	620	156
61	700(B)	129	153	2.00	4.13	13.67	--	--
62	1,400(T)	97	165	2.80	4.46	17.25	--	--
63	1,400(T)	96	340	2.46	11.10	24.00	--	--
66	1,400	98	--	1.94	--	--	609	228
69	1,400	103	61	--	--	--	--	--
70	700(D)	101	200	1.46	3.00	12.50	--	--
71	700(B)	101	112	1.71	2.69	8.90	--	--
72	700(L)	100	39	1.54	2.90	13.02	--	--
77	1,400	101	--	2.00	--	--	633	272
78	700	95	763	2.06	--	--	692	275
Mean							600	220

1/ The aircraft drop mode is given by the letter in parentheses: T = 700 gallons × two trail drops, B = bank attitude, D = dive attitude, L = loft attitude, HS = high speed drop (approximately 125 knots). All others were salvo drops made with the aircraft in a horizontal attitude at a normal drop speed (approximately 105 knots).

2/ Available data depended on movie film coverage. Where data are lacking, the drop release or empty point was out of the camera's view.

TABLE 17.--AIRCRAFT HEIGHT AND SPEED, AND DROP HISTORY AND TRAJECTORY FOR WATER

Drop No.	Load size and drop mode[1/]	Drop speed	Drop height	Drop history[2/] Time to exit tank	Time to reach ground	Time to settle	Drop trajectory Horizontal	Drop trajectory Vertical
	Gallons	*Knots*	*Feet*	*Seconds*			*Feet*	
1	700(HS)	127	178	1.88	5.02	18.88	525	168
2	1,400(HS)	128	409	1.84	14.94	--	577	175
6	1,400	120	294	1.81	9.92	17.65	--	--
10	700	103	166	1.85	3.75	14.83	--	--
20	700	92	285	1.98	8.04	20.10	519	223
23	1,400	105	157	1.85	3.83	14.65	--	--
24	700	102	178	1.88	4.88	17.29	473	166
29	1,400	103	528	1.83	17.85	33.65	553	196
30	700	111	550	1.92	19.44	--	568	277
32	700(HS)	128	393	2.02	14.94	--	499	143
37	1,400(T)	95	286	2.44	9.00	--	--	--
39	1,400(T)	102	137	2.60	3.79	15.56	--	--
44	700	110	1,091	1.99	--	--	--	--
49	1,400	94	--	--	--	--	--	--
55	1,400	98	538	1.71	15.85	28.69	530	230
56	700	95	785	2.00	--	12.96	--	--
58	1,400	100	1,046	1.90	--	17.71	449	105
67	1,400	106	--	--	--	--	--	--
82	1,400	92	--	--	--	--	--	--
83	700	101	--	1.83	--	--	441	248
Mean							513	190

1/ The aircraft drop mode is given by the letter in parentheses: T = 700 gallons × two trail drops, B = bank attitude, D = dive attitude, L = loft attitude, HS = high speed drop (approximately 125 knots). All others were salvo drops made with the aircraft in a horizontal attitude at a normal drop speed (approximately 105 knots).

2/ Available data depended on movie film coverage. Where data are lacking, the drop release or empty point was out of the camera's view.

TABLE 18.-

Area	Retardant dropped	Retardant coverage class							
No.	gallons	<0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99		
3	1,400	44.4	125.4	206.1		89.9		1,184	
4	700	113.7	99.2		89.0	84.1	24.9	87.6	91.0
5	700	28.6	74.2		75.4	56.5		205.2	
16	1,400	37.2	77.9	122.1	135.9	131.6	70.8	711.5	1,187
17	700	49.5	107.1	180.3	120.8	75.8	33.8	48.8	616 88.0
21	1,400	33.8	109.4	221.2	178.0	156.4	125.2		
35	1,400	27.7	97.3	137.9	180.7	166.4	164.8	386.8	1,162 83.0
36	700	49.9	96.5	222.4	98.9	31.8	18.2	22.9	541 77.3
37	700	46.9	126.3	164.1	123.3	101.1	20.5		589 84.1
38	1,400	29.5	129.3	192.2	212.7	256.4	139.9	231.3	1,191 85.1
45	700	20.9	105.9	292.8	140.4				577
46	1,400	20.1	115.9		476.0	127.7	5.4	0	1,122 80.1
50	1,400		--	-	122.7	81.9			--
51	700	34.6	102.4	122.8	91.6	33.7		139.7	
52	1,400	34.7	101.0	132.9	196.2	115.9	152.6	161.9	1,195
53	700			250.2	20.4		0	0	525 75.0
54	1,400			479.4	201.9	45.5	4.8	0	970 69.3
57	1,400	--			19.0	0	0	0	--
64	1,400	25.3	108.7		224.7	155.6	90.6	419.6	1,175
65	1,400	25.0	97.5	220.4	259.2	367.4	146.1	99.7	1,215 86.8
66	1,400	24.0			452.9	63.0		0	1,156 82.6
73	700	24.8	80.2	120.5	122.9	57.2	72.6	97.6	82.3
79	700	30.3	71.9	122.0	131.9	86.2	46.2	135.1	624 89.1
80	700	22.4	74.1		82.8	57.5	62.3		599 85.6
81	1,400	64.8	231.6	668.7	18.9	10.8	0	0	1,025 73.2

TABLE 19 - PHOS-CHEK VA [illegible] AREA AND TOTAL COVERAGE

Drop No.	Retardant coverage class							
	<0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	≥5.0	Total area
	square feet							
3	60,188	24,863	14,288	4,827	2,700	1,800	5,064	113,730
4	141,751	19,575	9,675	3,600	2,475	563	1,351	178,990
5	77,513	18,113	4,951	3,488	1,913	450	2,589	109,017
16	47,588	14,625	8,888	5,400	3,825	1,575	5,852	87,753
17	63,111	21,150	12,376	4,726	2,250	788	789	105,190
21	41,514	21,826	14,851	7,088	4,275	2,813	5,064	97,431
35	35,888	17,438	9,788	7,313	4,838	3,826	5,177	84,268
36	64,801	20,475	14,400	4,388	1,012	450	450	105,977
37	57,826	27,225	11,362	5,175	2,925	450	113	105,076
38	33,300	23,288	13,725	8,549	7,425	3,150	3,375	92,812
45	24,525	18,112	19,238	6,075	563			68,513
46	24,525	22,163	24,075	19,913	3,826			94,614
50	--	-	-	5,400	2,250	0	0	--
51	41,963	21,600	8,551	3,713	1,012	1,350	1,801	79,990
52	41,626	19,801	9,112	7,875	3,375	3,713		90,678
53	37,463	42,525	18,225	900	0	0	0	
54	50,737	34,537	33,975	8,550	1,351	113		129,263
57	--	-	37,800		0			
64	31,725	21,264	10,576		4,500	2,025	5,177	84,380
65	38,250	19,125	14,625	10,463	10,575	3,375	1,688	98,101
66	24,863	20,813	32,400	19,125	1,913	0	0	
73	29,475	15,638	8,438	5,063	1,688	1,575	1,239	63,116
79	36,358	15,076	8,775	5,401	2,475	1,013	1,689	70,787
80	24,750	15,300	8,663	3,375	1,688	1,350	2,365	57,491
81	85,062	41,963	48,589	2,025	338	0	0	177,977

TABLE 20.--GELGARD RECOVERY BY CONCENTRATION CLASS AND TOTAL RECOVERY

Drop No.	Retardant dropped	Concentration class							Total retardant recovered	Drop recovered
		<0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	≥5.0		
	Gallons	Gallons							Gallons	Percent
7	700	40.2	92.1	84.6	121.4	54.5	55.5	138.0	586	83.7
8	700	--	--	--	112.0	126.1	—	--	—	--
9	700	30.4	94.3	163.6	145.2	50.8	5.0	13.5	503	71.9
11	1,400	22.6	112.5	152.1	168.2	81.9	72.8	462.0	1,072	76.6
12	700	35.6	144.7	139.5	103.8	71.8	29.3	19.9	545	77.9
13	1,400	30.9	140.2	345.0	437.5	46.3	--	--	1,000	71.4
14	1,400	--	--	338.2	299.2	135.2	90.7	102.9	--	--
15	1,400	24.2	246.5	223.0	259.7	90.3	58.9	177.2	1,080	77.1
74	700	21.4	164.3	163.6	180.0	0	0	0	529	75.6
75	700	27.9	108.2	116.7	144.6	57.2	14.4	0	469	67.0
76	1,400	34.0	155.5	215.8	262.5	212.2	123.4	29.8	1,033	73.8

TABLE 21.--GELGARD COVERAGE AND CONCENTRATION AND TOTAL COVERAGE

Drop No.	Concentration class							Total area
	0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	≥5.0	
	Square feet							Square feet
7	47,138	18,563	5,963	4,950	1,575	1,238	1,914	81,341
8	--	--	--	3,600	3,600	—	—	--
9	31,050	16,538	11,813	6,075	1,350	113	226	67,165
11	28,687	21,375	10,913	6,863	2,363	1,688	5,177	77,066
12	38,813	28,575	10,238	4,275	2,026	675	338	84,940
13	33,638	31,613	22,163	17,550	1,350	--	--	106,314
14	--	--	22,388	11,925	4,050	2,025	1,801	--
15	25,875	50,513	15,638	10,463	2,700	1,350	3,150	109,689
74	21,150	34,650	10,800	7,650	0	0	0	74,250
75	28,913	23,288	7,876	5,851	1,801	338	0	68,067
76	37,238	31,613	14,288	10,462	6,188	2,813	563	103,165

TABLE 22.--FIRE-TROL 100 RECOVERY BY CONCENTRATION CLASS AND TOTAL RECOVERY

Drop No.	Retardant dropped	Concentration class							Total retardant recovered	Drop recovered
		<0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	≥5.0		
	Gallons	Gallons							Gallons	Percent
18	700	28.7	95.6	141.3	94.6	74.7	34.2	79.6	549	78.4
19	700	30.0	86.5	113.0	80.1	47.2	40.6	118.9	516	73.7
25	1,400	22.9	124.2	235.2	205.6	121.8	144.4	186.6	1,041	74.4
26	1,400	30.7	224.6	191.9	167.3	106.8	61.4	93.7	876	62.6
27	1,400	60.3	202.0	370.9	58.0	0	0	0	691	49.4
28	700	28.7	162.1	169.3	29.2	0	0	0	389	55.6
34	1,400	13.4	73.4	60.5	51.3	43.8	50.4	151.4	444	31.7
40	700	53.7	191.3	96.6	28.0	0	4.9	0	375	53.6
41	1,400	23.1	150.6	151.5	114.2	146.7	25.5	385.7	997	71.2
42	1,400	23.1	177.1	276.7	174.1	98.2	95.3	162.7	1,007	71.9
43	1,400	14.5	279.8	473.6	65.0	0	0	0	833	59.5
47	700	36.8	171.9	127.1	68.8	23.4	0	0	428	61.1
59	1,400	64.4	233.2	201.3	101.9	56.1	20.4	0	677	48.4
60	700	52.9	127.0	136.8	26.0	7.2	0	0	350	50.0
61	700	35.0	119.1	106.2	89.2	61.1	0	0	411	58.7
62	1,400	34.2	168.3	228.4	168.1	133.5	53.6	162.0	948	67.7
63	1,400	46.0	158.7	273.4	165.2	122.1	59.0	146.9	971	69.4
68	1,400	--	--	--	111.1	0	0	0	--	--
69	1,400	9.9	92.3	280.9	166.9	10.6	0	0	561	40.1
70	700	22.3	92.9	105.3	77.7	59.7	45.0	37.9	441	63.0
71	700	30.8	108.3	107.3	51.9	50.5	50.6	74.1	473	67.6
72	700	20.0	85.7	95.2	110.5	70.8	54.7	63.6	501	71.6
77	1,400	59.7	352.1	132.9	0	0	0	0	545	38.9
78	700	118.0	190.8	50.7	0	0	0	0	360	51.4

TABLE 23.--FIRE-TROL 100 COVERAGE BY CONCENTRATION CLASS AND TOTAL COVERAGE

Drop No.	Concentration class							Total area
	<0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	≥5.0	
	Square feet							
18	36,451	18,000	9,588	3,938	2,138	[illegible]	1,127	71,830
19	39,375	17,550	7,875	3,375	1,350	[illegible]	[illegible]	72,001
25	22,545	24,414	16,312	8,438	3,713	3,149	2,701	81,272
26	31,725	46,126	13,390	7,088	3,150	1,350	[illegible]	104,517
27	59,176	42,188	24,525	2,700	0	0	[illegible]	128,588
28	31,051	33,752	11,700	1,238	0	0	0	77,741
34	23,739	23,514	8,551	4,838	2,813	2,588	5,851	71,894
40	53,325	42,413	7,538	1,125	0	113	[illegible]	104,514
41	25,425	30,825	10,463	4,725	[illegible]	563	[illegible]	80,779
42	24,526	35,438	20,025	6,975	2,813	2,138	2,588	94,503
43	18,563	51,976	33,300	3,038	0	0	0	106,877
47	39,375	34,086	9,001	2,813	675	0	0	85,950
59	72,786	46,802	14,064	4,275	[illegible]	450	0	140,065
60	63,563	27,451	9,676	1,125	[illegible]	0	0	102,040
61	40,163	24,751	7,650	3,600	1,800	0	0	77,964
62	37,238	33,975	15,527	7,425	3,825	1,238	2,700	101,928
63	52,538	33,188	18,000	6,750	3,600	1,350	2,251	117,677
68	--	--	--	5,850	0	0	0	--
69	11,812	15,300	19,800	7,088	338	0	0	54,338
70	26,437	20,250	6,976	3,263	1,688	1,013	564	60,191
71	32,175	20,138	8,213	2,138	1,463	1,125	1,015	66,267
72	23,082	18,788	6,638	4,501	2,025	1,238	901	57,173
77	71,663	74,139	11,025	0	0	0	0	156,827
78	139,502	41,402	4,387	0	0	0	0	185,291

TABLE 24.--WATER RECOVERY BY CONCENTRATION CLASS AND TOTAL RECOVERY

Drop No.	Retardant dropped	Concentration class							Total retardant recovered	Drop recovered
		<0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	≥5.0		
	Gallons	Percent								
1	700	30.5	112.4	95.4	88.1	33.6	35.5	78.0	474	67.7
2	1,400	60.7	318.5	256.3	239.9	74.7	20.3	0	970	69.3
6	1,400	46.3	162.0	158.4	134.9	189.7	163.8	194.7	1,050	75.0
10	700	27.9	103.2	82.8	93.6	28.6	20.6	144.0	501	71.6
20	700	21.4	127.7	89.8	94.1	30.2	29.6	83.3	[illegible]	68.0
23	1,400	25.0	137.2	158.2	163.3	127.4	44.9	416.3	1,072	76.6
24	700	25.2	129.9	133.7	87.0	51.5	14.3	31.4	473	67.6
29	1,400	36.2	254.9	186.9	323.5	102.2	0	0	904	64.6
30	700	43.7	182.0	143.0	0	0	0	0	369	[illegible]
32	700	42.4	234.0	132.2	5.0	0	0	0	414	59.1
33	1,400	42.4	163.3	164.7	162.1	175.6	142.0	213.1	1,063	75.9
39	1,400	24.2	134.1	147.2	145.9	150.2	89.5	405.0	1,096	78.3
44	700	62.3	173.9	59.1	0	0	0	0	295	42.1
49	1,400	80.9	388.3	32.0	0	0	0	0	501	35.8
55	1,400	39.8	253.7	233.7	249.3	84.6	48.8	0	[illegible]	65.0
56	700	59.8	224.4	45.3	0	0	0	0	[illegible]	47.1
58	1,400	54.6	350.5	238.7	4.9	0	0	0	649	46.4
67	1,400	62.1	369.1	364.0	0	0	0	0	795	56.8
82	1,400	44.9	256.2	415.8	156.6	3.9	0	0	877	62.6
83	700	37.2	209.6	1.1	0	0	0	0	248	35.4

TABLE 25.--WATER COVERAGE BY CONCENTRATION CLASS AND TOTAL COVERAGE

Drop	Concentration class							
	<0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	≥5.0	Total area
	Square feet							Square feet
1	33,974	24,077	6,413	3,600	900	788	1,126	70,878
2	66,825	69,864	17,750	9,900	2,250	450	0	167,039
6	53,999	30,261	11,026	5,514	5,513	3,713	3,152	113,178
10	28,913	22,950	5,738	3,825	788	450	1,802	64,466
20	20,816	25,989	6,074	3,713	900	787	1,239	59,518
23	27,000	27,228	10,689	6,751	3,602	1,013	5,740	82,023
24	28,237	25,875	9,113	3,601	1,575	338	451	69,190
29	38,363	48,488	12,825	12,826	3,038	0	0	115,540
30	33,414	40,389	10,350	0	0	0	0	84,153
32	47,250	56,025	9,900	225	0	0	0	113,400
33	44,325	34,762	11,363	6,525	5,063	3,151	2,926	108,115
39	27,225	26,213	10,239	5,963	4,500	2,025	5,627	81,792
44	69,638	37,688	4,726	0	0	0	0	112,052
49	89,889	85,951	2,813	0	0	0	0	178,653
55	40,724	46,238	16,651	9,788	2,576	1,125	0	117,002
56	66,828	47,588	3,712	0	0	0	0	118,128
58	50,163	72,887	18,788	225	0	0	0	142,063
67	61,538	77,175	26,663	0	0	0	0	165,376
82	50,513	52,876	28,463	6,863	113	0	0	138,828
83	38,363	48,263	113	0	0	0	0	86,739

TABLE 26--DIMENSIONS OF PATTERN CONTOUR AREAS FOR PHOS-CHEK XA DROPS

Drop No.	Maximum contour area lengths at concentrations (≥gal/100 ft²) of...						Dimensions of contour areas, 2 gal/100 ft² coverage		
	0.2	0.5	1.0	2.0	3.0	4.0	Length at widths ≥(ft) of..: 5.0	10.0	Maximum width
	Feet						Feet		
3	799	723	673	499	370	264	454	423	57
4	469	408	333	241	118	108	237	230	49
5	420	340	247	207	128	81	198	192	68
16	445	386	344	254	157	128	247	241	104
17	506	423	379	266	140	57	264	263	59
21	509	468	389	318	274	202	300	283	110
35	576	529	485	408	335	245	368	358	86
36	460	371	353	174	111	41	171	168	75
37	560	373	328	203	85	35	192	182	70
38	674	531	473	331	285	142	322	314	125
45	489	413	341	198	6	0	185	159	78
46	548	486	442	370	173	17	363	358	115
50	--	--	--	253	45	0	221	207	46
51	486	356	328	208	116	104	204	200	54
52	482	446	388	329	253	188	305	300	102
53	489	411	244	21	0	0	11	0	9
54	515	454	364	206	64	6	192	188	72
57	--	498	304	44	0	0	23	0	9
64	535	463	398	291	122	106	283	280	123
65	468	423	373	263	232	154	257	252	130
66	547	411	363	240	59	0	231	226	133
73	436	388	354	244	153	94	238	235	64
79	463	384	334	286	191	150	280	274	80
80	446	375	364	331	231	133	301	257	69
81	508	454	338	114	10	0	96	83	45

TABLE 27.--DIMENSIONS OF PATTERN CONTOUR AREAS FOR GELGARD DROPS

Drop No.	Maximum contour area lengths at concentrations (≥gal/100 ft²) of...						Dimensions of contour areas, ² gal/100 ft² coverage		
							Length at widths ≥(ft) of..		
	0.2	0.5	1.0	2.0	3.0	4.0	5.0	10.0	Maximum width
	Feet						Feet		
7	486	398	319	251	144	123	246	241	58
8	--	--	--	136	27	0	126	115	75
9	406	360	295	200	90	36	190	179	55
11	454	377	309	264	139	122	261	258	137
12	456	373	341	141	79	47	140	137	79
13	497	376	316	249	31	0	243	239	124
14	--	429	359	280	135	87	271	263	137
15	456	430	347	255	129	88	250	245	112
74	596	572	528	156	0	0	149	135	35
75	416	319	286	238	114	28	238	222	63
76	466	416	329	230	164	88	227	224	132

TABLE 28.--DIMENSIONS OF PATTERN CONTOUR AREAS FOR FIRE-TROL 100 DROPS

Drop No.	Maximum contour area lengths at concentrations (≥gal/100 ft²) of...						Dimensions of contour areas, ² gal/100 ft² coverage		
							Length at widths ≥(ft) of..		
	0.2	0.5	1.0	2.0	3.0	4.0	5.0	10.0	Maximum width
	Feet						Feet		
18	486	419	314	196	119	78	176	165	62
19	456	395	337	231	134	114	215	167	66
25	534	424	372	267	166	138	261	257	117
26	433	366	204	168	135	106	164	120	166
27	455	266	215	66	0	0	60	55	39
28	483	331	202	41	0	0	34	27	30
34	535	459	363	305	216	202	298	289	82
40	390	256	141	30	0	0	23	6	11
41	500	433	387	286	154	134	255	237	109
42	552	454	391	166	141	104	150	145	133
43	440	386	303	131	0	0	88	82	64
47	480	398	231	89	38	0	84	80	64
59	434	374	222	161	95	9	156	148	79
60	350	288	175	39	8	0	27	21	39
61	418	345	288	150	107	0	142	131	48
62	706	554	520	375	304	169	345	305	88
63	598	443	358	275	260	136	255	221	116
68	--	--	--	114	0	0	110	104	76
69	281	263	243	144	6	0	139	137	86
70	335	273	230	213	151	80	207	201	61
71	366	325	256	151	120	107	149	145	53
72	442	376	342	280	189	140	255	249	60
77	484	423	241	0	0	0	0	0	0
78	376	226	100	0	0	0	0	0	0

TABLE 29.--DIMENSIONS OF PATTERN CONTOUR AREAS FOR WATER DROPS

Drop No.	Maximum contour area lengths at concentrations (≥gal/100 ft²) of... 0.2	0.5	1.0	2.0	3.0	4.0	Dimensions of contour areas, 2 gal/100 ft² coverage: Length at widths ≥(ft) of.. 5.0	10.0	Maximum width
	Feet						Feet		
1	419	370	231	156	77	73	151	147	65
2	506	405	254	163	72	14	159	154	132
6	481	441	338	199	165	136	184	176	148
10	431	314	261	216	109	84	203	171	63
20	442	365	194	143	100	82	141	138	73
23	519	401	358	318	258	134	306	284	149
24	441	379	284	184	86	28	174	156	73
29	440	386	249	182	89	0	169	164	142
30	374	253	174	0	0	0	0	0	0
32	429	254	179	12	0	0	9	6	15
33	506	404	334	218	179	153	213	197	122
39	682	591	526	465	375	309	456	452	71
44	350	181	94	0	0	0	0	0	0
49	533	418	72	0	0	0	0	0	0
55	452	409	279	160	94	41	145	141	148
56	415	328	101	0	0	0	0	0	0
58	540	394	299	19	0	0	13	6	12
67	459	376	339	0	0	0	0	0	0
82	446	368	312	149	0	0	106	101	61
83	308	195	0	0	0	0	0	0	0

TABLE 30.--PREDICTED VALUES FOR PERCENT OF PHOS-CHEK XA RECOVERED BY CONCENTRATION CLASS (RETARDANT DISTRIBUTION)

Drop height	Concentration (≥gal/100 ft²)								
	0.2	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
	[illegible]								
700-GALLON DROP									
100	78	77	71	61	55	48	40	34	32
150	78	77	70	59	52	45	37	31	28
200	77	76	68	56	49	42	33	27	25
250	77	76	67	53	45	38	30	23	19
300	77	76	66	51	42	35	26	20	16
400	76	75	63	45	35	28	20	14	10
500	76	74	59	39	29	22	15	10	6
600	75	73	56	34	25	17	11	6	3
800	73	70	49	24	15	9	5	2	1
1,000	71	67	42	17	9	5	2	1	0
1,200	68	63	35	11	5	2	1	0	0
1,400	66	59	30	8	3	1	0	0	0
1,600	62	55	24	5	1	1	0	0	0
1,800	58	51	20	3	1	0	0	0	0
2,000	55	47	16	2	0	0	0	0	0
1,400-GALLON DROP									
100	84	81	78	76	73	70	66	62	58
150	84	81	78	75	72	68	64	59	54
200	84	81	78	75	71	66	64	55	50
250	84	81	77	74	70	64	57	51	45
300	84	81	77	73	68	62	54	46	40
400	83	81	77	72	65	56	47	38	32
500	82	80	76	69	61	51	40	31	24
600	82	80	75	67	57	47	34	24	18
800	80	78	72	63	48	35	25	14	9
1,000	78	76	69	54	39	26	15	8	5
1,200	76	74	67	47	31	18	9	4	2
1,400	73	72	61	40	23	12	5	2	1
1,600	71	69	57	33	17	8	3	1	0
1,800	68	67	52	27	12	5	2	0	0
2,000	65	63	48	21	8	3	1	0	0

TABLE 31.--PREDICTED VALUES FOR PERCENT OF GELGARD RECOVERED BY CONCENTRATION CLASS (RETARDANT DISTRIBUTION)

Drop height	Concentration (≥gal/100 ft²)								
	0.2	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
	[illegible]								
700-GALLON DROP									
100	76	72	65	57	50	44	38	34	31
150	75	72	64	55	49	42	34	28	26
200	75	71	63	54	47	39	29	22	20
250	74	71	61	52	45	36	24	16	14
300	74	70	60	50	42	33	19	11	10
400	73	69	57	45	38	27	12	4	4
500	72	68	54	41	33	22	6	2	1
600	71	66	51	37	28	17	3	0	0
800	68	63	45	28	20	10	1	0	0
1,000	65	59	38	21	14	5	0	0	0
1,200	62	55	32	15	9	2	0	0	0
1,400	59	51	27	11	6	1	0	0	0
1,600	55	47	22	8	4	0	0	0	0
1,800	52	43	18	5	2	0	0	0	0
2,000	48	39	14	3	1	0	0	0	0
1,400-GALLON DROP									
100	74	73	70	66	54	46	43	39	37
150	74	73	69	65	53	45	40	36	34
200	73	72	68	63	52	44	38	31	30
250	73	72	67	62	50	42	36	27	25
300	72	71	66	60	49	41	33	23	21
400	72	70	64	57	45	38	28	15	12
500	70	69	62	54	42	35	23	9	6
600	69	68	60	51	39	32	19	5	3
800	67	65	56	45	33	26	12	1	0
1,000	64	62	52	39	28	21	7	0	0
1,200	61	58	47	34	23	17	4	0	0
1,400	57	55	43	29	19	13	2	0	0
1,600	54	51	39	24	16	11	1	0	0
1,800	51	48	35	21	13	8	1	0	0
2,000	47	44	31	17	10	6	0	0	0

TABLE 32.- PREDICTED VALUES FOR PERCENT OF FIRE-TROL 100 RECOVERED BY CONCENTRATION CLASS (RETARDANT DISTRIBUTION)

Drop height	Concentration (>gal/100 ft²)								
	0.2	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Percent									
700-GALLON DROP									
100	65	60	52	45	38	32	26	22	19
150	64	59	49	41	34	28	24	20	17
200	62	57	46	36	30	25	20	17	15
250	61	55	42	32	25	21	17	14	13
300	59	52	39	27	21	17	14	12	10
400	55	48	32	19	13	11	9	7	7
500	51	43	26	13	8	6	5	4	4
600	47	39	21	8	4	3	3	2	2
800	38	30	12	3	1	1	1	1	0
1,000	31	23	7	1	0	0	0	0	0
1,200	25	17	3	0	0	0	0	0	0
1,400	19	12	2	0	0	0	0	0	0
1,600	15	9	1	0	0	0	0	0	0
1,800	11	6	0	0	0	0	0	0	0
2,000	8	4	0	0	0	0	0	0	0
1,400-GALLON DROP									
100	72	69	63	58	52	47	42	37	33
150	71	68	62	57	51	45	39	34	30
200	70	67	61	55	49	43	37	31	27
250	69	65	59	53	47	40	33	27	23
300	68	64	58	51	44	37	29	23	20
400	65	60	54	46	38	29	21	16	13
500	62	57	49	41	31	22	14	10	8
600	58	53	44	35	24	15	8	5	5
800	51	45	34	23	13	5	2	1	1
1,000	45	37	25	14	5	1	0	0	0
1,200	38	30	18	7	2	0	0	0	0
1,400	32	24	12	3	0	0	0	0	0
1,600	27	18	7	1	0	0	0	0	0
1,800	22	14	4	1	0	0	0	0	0
2,000	18	10	2	0	0	0	0	0	0

TABLE 33.--PREDICTED VALUES FOR PERCENT OF WATER RECOVERED BY CONCENTRATION CLASS (RETARDANT DISTRIBUTION)

Drop height	Concentration (>gal/100 ft²)								
	0.2	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Percent									
700-GALLON DROP									
100	68	61	52	47	43	38	28	24	23
150	66	59	51	45	41	35	25	21	20
200	64	57	49	41	36	31	21	17	16
250	62	55	46	36	31	25	17	13	12
300	60	53	43	30	24	18	12	9	8
400	55	48	35	18	11	7	5	4	3
500	50	44	27	8	3	2	1	1	1
600	45	39	19	2	1	0	0	0	0
800	36	29	8	0	0	0	0	0	0
1,000	28	21	2	0	0	0	0	0	0
1,200	21	14	0	0	0	0	0	0	0
1,400	15	10	0	0	0	0	0	0	0
1,600	11	6	0	0	0	0	0	0	0
1,800	7	4	0	0	0	0	0	0	0
2,000	5	2	0	0	0	0	0	0	0
1,400-GALLON DROP									
100	76	71	65	62	57	51	46	41	38
150	75	70	64	65	56	50	45	40	36
200	74	69	63	59	54	48	43	39	34
250	73	76	61	57	51	45	41	36	30
300	72	66	59	54	48	41	36	33	25
400	69	62	54	48	40	31	25	22	14
500	66	59	49	42	32	20	12	10	6
600	63	55	44	35	23	10	4	3	1
800	56	47	34	23	10	1	0	0	0
1,000	50	39	25	13	3	0	0	0	0
1,200	43	32	18	7	1	0	0	0	0
1,400	37	26	12	3	0	0	0	0	0
1,600	31	20	8	1	0	0	0	0	0
1,800	26	16	5	0	0	0	0	0	0
2,000	22	12	3	0	0	0	0	0	0

TABLE 51.--DATA LIMITS, FIT OF EQUATION TO DATA (R^2), AND STANDARD ERROR ($s_{y.x_i}$) FOR RECOVERY MODELS FOR EACH RETARDANT AT EACH LOAD [illegible]

Retardant	Drop height limits	Load of [illegible]	R^2	$s_{y.x_i}$
		700-GALLON DROP		
Phos-Chek XA	51-1,046	0.	.99	6.4
		1.0	.9	11.3
		2.0	.97	8.3
		3.0	.99	3.6
		4.0	.9	2.3
Gelgard	147-1,000	0.2	.99	6.7
		1.0	.98	9.7
		2.0	.94	[illegible]
		3.0	.99	2.1
		4.0	.99	2.2
Fire-Trol 100	39-1,043	0.2	.9[illegible]	[illegible]
		1.0	.94	11.0
		2.0	.90	9.7
		3.0	.80	9.1
		4.0	.64	8.1
Water	166-1,073	0.2	.99	5.8
		1.0	.99	4.4
		2.0	.94	6.5
		3.0	.89	5.4
		4.0	.76	6.3
		1,400-GALLON DROP		
Phos-Chek XA	128-2,000	0.2	.99	9.6
		1.0	.99	7.5
		2.0	.97	9.6
		3.0	.97	7.1
		4.0	.99	3.5
Gelgard	164-982	0.2	.99	4.4
		1.0	.99	8.1
		2.0	.98	7.3
		3.0	.9[illegible]	9.8
		4.0	.97	4.8
Fire-Trol 100	157-1,500	0.2	.98	8.2
		1.0	.98	6.5
		2.0	.97	4.9
		3.0	.99	[illegible]
		4.0	.99	1.6
Water	137-1,500	0.2	.99	7.1
		1.0	.98	[illegible]
		2.0	.99	1.2
		3.0	.99	1.5
		4.0	.99	1.8

1/ R^2 is the coefficient of multiple determination and is a measure of how well the regression fits the data. $s_{y.x_i}$ is the standard error of the estimate.

2/ The limits on recovery by concentration class for all models are from 0.2 to 4.0 gal/100 ft^2.

TABLE 35.--PREDICTIONS OF AREA OF COVERAGE AS A FUNCTION OF DROP HEIGHT AND CONCENTRATION FOR 700- AND 1,400-GALLON PHOS-CHEK XA DROPS

Drop height	Concentration (gal/100 ft²)								
	0.2	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
	Area of coverage (ft.²)								
	700-GALLON DROP								
100	33,783	26,670	18,170	12,514	8,900	6,461	4,754	3,611	2,987
150	35,011	27,588	18,625	12,702	8,960	6,465	4,715	3,437	2,688
200	36,225	28,473	19,030	12,844	8,987	6,457	4,607	3,159	2,338
250	37,423	29,319	19,385	12,947	8,994	6,421	4,412	2,792	1,968
300	38,600	30,123	19,690	13,014	8,994	6,337	4,122	2,365	1,606
400	40,873	31,592	20,155	13,069	8,946	5,975	3,287	1,477	978
500	43,010	32,857	20,446	13,071	8,761	5,310	2,269	754	531
600	44,978	33,903	20,592	13,029	8,372	4,372	1,320	310	258
800	48,292	35,317	20,628	12,579	6,879	2,212	244	26	
1,000	50,612	35,885	20,367	11,390	4,672	687	17	1	
1,200	51,810	35,860	19,492	9,408	2,482	117			
1,400	51,885	35,212	17,839	6,913	978	10			
1,600	50,843	33,704	15,438	4,413	272				
1,800	48,671	31,303	12,505	2,393	51				
2,000	45,482	28,109	9,395	1,079	6				
	1,400-GALLON DROP								
100	43,276	42,484	31,146	18,878	15,905	14,670	12,052	9,128	7,571
150	44,732	43,833	32,286	19,822	16,799	15,342	12,383	9,255	7,624
200	46,192	45,183	33,429	20,765	17,666	15,937	12,609	9,300	7,634
250	47,654	46,532	34,572	21,703	18,500	16,445	12,731	9,284	7,624
300	49,115	47,878	35,712	22,630	19,290	16,859	12,754	9,916	7,571
400	52,028	50,553	37,970	24,435	20,711	17,386	12,518	8,748	7,245
500	54,915	53,190	40,181	26,142	21,870	17,509	11,866	7,934	6,550
600	57,758	55,771	42,320	27,713	22,721	17,253	10,836	6,824	5,498
800	63,236	60,691	46,282	30,303	23,412	15,541	8,033	4,242	2,919
1,000	68,307	65,160	49,657	31,962	22,798	12,581	5,058	2,050	973
1,200	72,814	69,025	52,258	32,548	20,859	9,112	2,690	756	185
1,400	76,601	72,135	53,922	32,051	17,862	5,886	1,203	210	18
1,600	79,519	74,349	54,507	30,475	14,285	3,383	451	43	1
1,800	81,424	75,530	53,897	27,953	10,654	1,727	141	6	
2,000	82,160	75,470	52,212	24,721	7,400	782	37	1	

TABLE 36.--PREDICTIONS OF AREA OF COVERAGE AS A FUNCTION OF DROP HEIGHT AND CONCENTRATION FOR 700- AND 1,400-GALLON GELGARD DROPS

Drop height	Concentration (gal/100 ft²)								
	0.2	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
	Area of coverage (ft.²)								
	700-GALLON DROP								
100	34,991	24,026	13,688	10,245	8,385	6,633	5,212	4,196	3,852
150	36,411	25,691	14,587	10,566	8,499	6,648	5,145	3,787	3,567
200	37,768	27,315	15,436	10,841	8,577	6,649	4,948	3,080	2,591
250	39,056	28,885	16,228	11,071	8,624	6,642	4,577	2,176	1,682
300	40,271	30,386	16,954	11,258	8,650	6,609	4,015	1,288	885
400	42,473	33,141	18,197	11,518	8,661	6,395	2,495	229	108
500	44,356	35,512	19,147	11,652	8,652	5,878	1,064	13	3
600	45,919	37,459	19,815	11,701	8,587	5,018	279		
800	47,171	38,978	20,255	11,707	8,408	3,884	40		
1,000	49,307	41,281	20,558	11,502	6,795	791			
1,200	49,747	41,570	20,478	10,299	4,858	109			
1,400	49,810	41,550	19,891	9,395	2,790	6			
1,600	49,747	41,107	18,356	7,347	1,218				
1,800	49,307	39,620	15,676	5,010	383				
2,000	48,138	36,607	12,071	2,891	82				
	1,400-GALLON DROP								
100	48,881	32,818	28,264	22,380	15,603	10,306	7,606	6,473	5,991
150	51,569	34,630	29,435	23,226	16,336	11,030	8,106	6,520	5,895
200	54,220	36,445	30,581	24,024	16,999	11,633	8,432	6,528	5,942
250	56,829	38,260	31,699	24,770	17,585	12,111	8,610	6,524	5,823
300	59,391	40,067	32,783	25,460	18,091	12,465	8,680	6,490	5,597
400	64,355	43,636	34,829	26,660	18,362	12,851	8,683	6,193	4,743
500	69,074	47,103	36,683	27,607	19,329	12,938	8,454	5,426	3,421
600	73,514	50,421	38,317	28,298	19,542	12,908	7,659	4,171	1,986
800	81,440	56,432	40,837	28,980	19,545	12,004	4,231	1,388	278
1,000	87,936	61,351	42,309	29,017	18,876	9,255	1,033	158	8
1,200	92,891	64,958	42,821	28,472	17,028	5,353	79	4	
1,400	96,380	67,162	42,671	27,000	13,992	2,120	1		
1,600	98,188	68,042	41,701	24,522	10,253	528			
1,800	98,835	67,936	39,704	21,182	6,575	76			
2,000	98,650	66,748	36,600	17,298	3,627	6			

TABLE 37.--PREDICTIONS OF AREA OF COVERAGE AS A FUNCTION OF DROP HEIGHT AND CONCENTRATION FOR 700- AND 1,400-GALLON FLEET-APPLIED DROPS

Drop height	Concentration (gal/100 ft²)								
	0.2	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
	Area (ft²)								
	700-GALLON DROP								
100	49,805	27,511	14,579	10,810	7,507	5,171	3,467	2,375	1,580
150	49,817	27,419	14,482	10,655	7,020	4,727	3,083	2,026	1,280
200	49,046	27,273	14,325	10,228	6,489	4,264	2,645	1,641	1,116
250	48,466	27,167	14,098	9,744	6,177	3,611	2,194	1,275	768
300	47,765	26,787	13,795	9,389	5,845	3,482	1,763	947	499
400	46,667	26,056	13,370	8,868	5,760	3,052	1,953	461	176
500	44,816	25,038	11,562	8,018	2,592	1,133	544	191	49
600	41,668	23,733	10,305	4,223	1,407	700	256	68	11
800	36,329	20,493	7,595	1,645	864	175	41	6	
1,000	30,382	16,622	4,130	480	141	30	4		
1,200	24,862	12,602	2,329	73	36	1			
1,400	19,310	8,866	930	5	5				
1,600	14,504	5,581	306	1	1				
1,800	10,860	3,491	62						
2,000	7,736	1,950	17						
	1,400-GALLON DROP								
100	51,575	30,547	16,892	13,663	11,910	10,165	9,700	7,665	6,412
150	52,404	31,126	16,987	13,708	11,971	10,488	9,214	8,127	6,654
200	53,656	31,342	17,182	13,879	11,964	9,913	8,508	6,954	5,734
250	53,196	32,062	17,216	13,261	11,086	8,697	6,286	4,707	3,487
300	52,008	31,134	16,830	12,114	10,172	8,031	5,575	4,178	2,975
400	50,140	29,874	15,589	11,003	8,802	6,750	4,111	3,129	1,966
500	48,177	28,317	14,065	10,015	7,911	5,869	3,709	2,256	1,432
600	45,316	27,487	13,477	8,869	6,820	4,852	3,265	1,432	1,020
800	40,084	24,702	11,019	5,068	2,078	1,249	571	520	
1,000	34,380	21,626	7,586	1,067	1,407	476	73	61	
1,200	27,140	16,774	4,118	1,134	495	38	4	4	
1,400	21,073	13,472	2,342	648	51	5			
1,600	15,883	10,186	1,267	321					
1,800	10,988	6,142	1,106	21					
2,000	7,238	3,064	1,078	1					

TABLE 38.--PREDICTIONS OF AREA OF COVERAGE AS A FUNCTION OF DROP HEIGHT AND CONCENTRATION FOR 700- AND 1,400-GALLON WATER DROPS

Drop height	Concentration (gal/100 ft²)								
	0.2	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
	Area (ft²)								
	700-GALLON DROP								
100	53,285	33,948	14,631	10,152	7,026	4,755	3,317	2,386	2,384
150	55,569	33,492	14,422	10,136	6,956	4,663	3,284	2,487	2,124
200	57,780	32,870	14,525	10,064	6,724	4,420	3,122	2,254	1,782
250	59,919	32,091	14,022	9,727	6,248	3,989	2,622	1,852	1,346
300	61,945	31,169	13,299	9,248	5,455	3,180	2,025	1,315	996
400	65,541	28,955	12,367	7,457	3,510	1,272	698	359	249
500	65,536	26,550	10,755	4,929	509	173	73	22	
600	60,128	23,497	6,665	2,158	95	4	1		
800	50,066	17,586	4,459	77					
1,000	45,577	12,144	1,571						
1,200	37,560	7,741	654						
1,400	28,460	4,565	47						
1,600	19,770	2,479	4						
1,800	12,605	1,246							
2,000	7,582	579							
	1,400-GALLON DROP								
100	62,654	41,254	26,180	20,724	17,796	14,881	12,824	9,275	7,226
150	65,812	43,641	27,485	21,774	18,817	14,964	14,785	8,487	7,166
200	66,763	45,866	27,644	21,984	17,615	14,960	12,466	9,756	6,936
250	62,690	47,887	26,872	21,864	17,736	14,528	11,806	8,576	5,487
300	64,575	46,216	29,436	23,761	17,251	13,822	11,811	7,532	5,236
400	70,159	50,709	30,239	21,548	14,884	12,406	9,134	6,954	5,017
500	75,386	52,691	30,736	21,422	13,434	9,984	7,124	5,466	3,972
600	80,195	54,564	31,665	20,134	12,674	8,771	5,894	3,766	2,787
800	87,518	57,686	30,232	14,108	4,945	1,967	611	14	
1,000	92,655	60,736	27,864	10,470	1,908	196	1		
1,200	94,605	66,841	21,915	6,871	586	1			
1,400	94,359	68,200	18,244	2,134	47				
1,600	91,645	69,727	13,761	480	1				
1,800	86,005	64,099	9,115	194					
2,000	77,852	57,821	4,492	28					

TABLE 39.--DATA LIMITS, FIT OF EQUATION TO DATA (R^2), AND STANDARD ERROR ($sy.x_i$) FOR AREA OF COVERAGE MODELS FOR EACH RETARDANT AND LOAD SIZE[1/]

Retardant	Drop height limits	Level of coverage[2/]	R^2	$sy.x_i$
	Feet	Gal/100 ft^2		
700-GALLON DROP				
Phos-Chek XA	128-2,000	0.2	0.98	7,116
		1.0	.98	3,607
		2.0	.89	3,211
		3.0	.99	497
		4.0	.96	470
Gelgard	147-1,000	0.2	.98	7,429
		1.0	.99	1,811
		2.0	.98	1,546
		3.0	.96	747
		4.0	.98	309
Fire-Trol 100	39-1,043	0.2	.87	15,278
		1.0	.96	2,647
		2.0	.93	1,623
		3.0	.86	1,101
		4.0	.70	940
Water	166-1,073	0.2	.99	2,553
		1.0	.92	3,079
		2.0	.99	568
		3.0	.96	434
		4.0	.75	689
1,400-GALLON DROP				
Phos-Chek XA	128-2,000	0.2	.99	6,219
		1.0	.99	4,970
		2.0	.92	5,538
		3.0	.93	2,655
		4.0	.98	752
Gelgard	164-982	0.2	.94	20,201
		1.0	.99	3,941
		2.0	.99	624
		3.0	.98	1,272
		4.0	.99	811
Fire-Trol 100	157-1,500	0.2	.86	27,249
		1.0	.97	5,002
		2.0	.95	2,638
		3.0	.98	806
		4.0	.96	680
Water	137-1,500	0.2	.99	4,564
		1.0	.95	6,549
		2.0	.99	944
		3.0	.98	1,036
		4.0	.99	538

[1/] R^2 is the coefficient of multiple determination and is a measure of how well the regression fits the data. $sy.x_i$ is the standard error of the estimate.

[2/] The limits on recovery by concentration class for all models are from 0.2 to 4.0 gal/100 ft^2.

TABLE 40.--PREDICTED VALUES FOR CONTOUR AREA LENGTHS BY CONCENTRATION CLASS FOR PHOS-CHEK XA

Drop height	Length of contour areas at concentrations (≥gal/100 ft^2) of ...								
	0.2	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
	Feet								
700-GALLON DROP									
100	406	368	319	295	257	217	175	147	120
150	417	377	328	293	256	211	165	140	113
200	426	385	335	290	255	204	155	131	105
250	435	392	341	285	253	196	145	120	95
300	442	399	344	279	249	186	134	109	84
400	453	408	344	263	238	164	113	87	62
500	461	415	334	241	219	140	93	66	43
600	466	419	317	216	192	116	75	47	27
800	470	422	266	161	121	72	47	22	9
1,000	470	422	205	108	54	40	28	8	2
1,200	470	419	141	65	15	8	0	0	0
1,400	469	408	89	35	2	0	0	0	0
1,600	461	385	52	15	0	0	0	0	0
1,800	442	346	28	7	0	0	0	0	0
2,000	406	293	15	3	0	0	0	0	0
1,400-GALLON DROP									
100	448	424	368	319	274	247	209	175	152
150	458	435	376	325	279	250	212	177	155
200	467	441	382	331	284	252	214	179	158
250	477	449	390	336	288	254	215	180	159
300	485	456	396	341	292	256	215	180	159
400	501	470	409	351	298	259	215	179	158
500	515	482	421	358	304	260	215	176	152
600	527	492	430	365	308	260	213	168	142
800	545	508	430	371	312	260	201	137	112
1,000	548	487	409	367	317	255	172	93	75
1,200	532	478	385	334	308	245	129	50	43
1,400	515	430	332	333	298	217	82	21	20
1,600	446	417	311	312	283	203	42	9	6
1,800	464	390	259	288	264	174	17	3	1
2,000	475	344	197	226	239	141	5	1	0

TABLE 41.--PREDICTED VALUES FOR CONTOUR AREA LENGTHS BY CONCENTRATION CLASS FOR GELGARD

Drop height	Length of contour areas at concentrations (>gal/100 ft^2) of...								
	0.2	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
	Feet								
700-GALLON DROP									
100	439	581	513	270	213	172	144	126	118
150	445	586	517	271	211	170	141	120	110
200	449	591	520	271	208	167	137	111	98
250	454	595	524	271	205	163	130	96	83
300	458	599	527	271	202	159	120	78	65
400	465	607	532	269	195	148	90	39	33
500	470	612	535	266	187	134	55	12	12
600	475	617	538	262	179	120	26	2	0
800	480	625	541	251	161	89	2	0	0
1,000	481	624	539	238	144	60	0	0	0
1,200	480	622	532	225	126	37	0	0	0
1,400	475	617	522	206	109	21	0	0	0
1,600	465	606	507	188	94	11	0	0	0
1,800	449	590	489	170	79	5	0	0	0
2,000	428	569	467	151	66	2	0	0	0
1,400-GALLON DROP									
100	441	589	516	283	240	181	149	138	133
150	447	594	520	288	240	181	149	137	128
200	451	599	523	292	240	181	148	135	122
250	456	605	526	296	240	180	148	132	113
300	460	607	529	300	240	180	146	126	107
400	467	614	533	306	239	179	139	110	90
500	473	620	537	309	237	176	126	90	73
600	477	624	540	309	234	170	106	67	57
800	482	629	541	299	223	148	55	26	26
1,000	483	630	540	278	207	109	16	9	8
1,200	482	629	534	250	186	61	1	1	0
1,400	477	625	524	227	161	25	0	1	0
1,600	467	622	520	204	134	3	0	0	0
1,800	451	620	282	181	107	1	0	0	0
2,000	430	614	271	159	81	0	0	0	0

TABLE 42.--PREDICTED VALUES FOR CONTOUR AREA LENGTHS BY CONCENTRATION CLASS FOR FIRE-TROL 100

Drop height	Length of contour areas at concentrations (≥gal/100 ft²) of...								
	0.2	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
	Feet								
700-GALLON DROP									
100	392	325	302	260	219	188	165	146	131
150	408	335	298	246	198	166	144	127	114
200	422	343	291	229	175	143	123	109	97
250	435	349	281	211	153	120	103	91	82
300	446	353	270	193	131	100	85	75	67
400	461	346	244	156	92	65	55	48	44
500	466	329	216	122	62	40	33	29	27
600	461	307	187	93	39	23	19	17	16
800	422	255	134	49	14	7	5	5	5
1,000	357	200	91	24	4	2	1	1	1
1,200	278	150	58	11	1	0	0	0	0
1,400	201	108	36	4	0	0	0	0	0
1,600	134	75	21	2	0	0	0	0	0
1,800	83	50	12	1	0	0	0	0	0
2,000	47	32	6	0	0	0	0	0	0
1,400-GALLON DROP									
100	450	407	349	289	239	205	173	147	127
150	455	412	352	284	235	204	172	147	126
200	458	416	350	279	229	202	171	145	124
250	460	419	345	273	224	200	169	143	121
300	461	420	339	267	217	197	165	139	117
400	458	415	325	253	204	186	152	125	104
500	450	405	308	238	189	170	128	104	86
600	440	392	290	222	175	149	96	77	64
800	411	359	251	191	146	96	31	26	25
1,000	377	322	213	160	118	47	3	3	3
1,200	338	283	176	132	94	16	0	0	0
1,400	297	243	143	106	73	4	0	0	0
1,600	256	206	114	85	56	1	0	0	0
1,800	217	171	89	66	42	0	0	0	0
2,000	181	139	68	51	31	0	0	0	0

TABLE 43.--PREDICTED VALUES FOR CONTOUR AREA LENGTHS BY CONCENTRATION CLASS FOR WATER

Drop height	Length of contour areas at concentrations (≥gal/100 ft²) of...								
	0.2	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
	Feet								
700-GALLON DROP									
100	440	326	271	237	203	172	143	115	86
150	439	319	262	228	194	163	137	111	77
200	437	310	252	217	181	148	126	104	66
250	434	301	242	204	164	129	109	92	54
300	431	292	230	190	144	106	89	76	41
400	421	272	206	158	102	60	46	39	20
500	409	251	181	125	64	25	15	12	8
600	394	231	157	95	34	8	3	2	2
800	355	191	113	47	7	0	0	0	0
1,000	309	156	78	20	1	0	0	0	0
1,200	258	124	51	7	0	0	0	0	0
1,400	206	97	33	2	0	0	0	0	0
1,600	158	75	20	1	0	0	0	0	0
1,800	116	57	12	0	0	0	0	0	0
2,000	81	43	7	0	0	0	0	0	0
1,400-GALLON DROP									
100	476	407	351	315	286	259	235	208	144
150	479	409	350	311	277	246	222	198	141
200	482	412	348	305	266	229	207	187	136
250	484	413	345	299	254	211	189	172	130
300	486	415	342	292	240	192	170	156	122
400	489	417	334	277	210	153	132	122	101
500	491	418	325	259	179	117	97	88	77
600	492	417	315	240	150	85	67	59	53
800	493	411	291	201	97	40	28	22	19
1,000	493	400	265	162	58	16	9	6	4
1,200	493	384	237	126	32	6	3	1	1
1,400	492	364	209	96	16	2	1	0	0
1,600	489	339	181	70	8	0	0	0	0
1,800	482	311	155	50	3	0	0	0	0
2,000	470	281	130	35	1	0	0	0	0

TABLE 44.--DATA LIMITS, FIT OF EQUATION TO DATA (R^2), AND STANDARD ERROR ($sy.x_i$) FOR CONTOUR AREA LENGTH MODELS FOR EACH RETARDANT AND LOAD SIZE[1/]

Retardant	Drop height limits	Level of coverage[2/]	R^2	$sy.x_i$
		700-GALLON DROP		
Phos-Chek XA	51-1,046	0.2	0.99	47
		1.0	97	60
		2.0	.95	5
		3.0	96	1
		4.0	.94	27
Gelgard	147-1,000	0.2	.99	7
		1.0	.98	54
		2.0	9	53
		3.0	.91	10
		4.0	.93	5
Fire-Trol 100	59-1,043	0.2	9	7
		1.0	.97	49
		2.0	95	50
		3.0	.93	37
		4.0	.93	18
Water	166-1,073	0.2	.99	18
		1.0	.91	61
		2.0	.97	28
		3.0	.90	26
		4.0	.7	29
		1,100-GALLON DROP		
Phos-Chek XA	128-2,000	0.2	.98	75
		1.0	.99	10
		2.0	.97	100
		3.0	.94	47
		4.0	.90	57
Gelgard	164-982	0.2	.99	12
		1.0	99	7
		2.0	.98	38
		3.0	.97	
		4.0	.97	19
Fire-Trol 100	157-1,500	0.2	96	67
		1.0	.96	66
		2.0	.95	50
		3.0	90	62
		4.0	97	7
Water	137-1,500	0.2	.97	101
		1.0	1	110
		2.0	94	72
		3.0	2	52
		4.0	9	56

[1] R^2 is the coefficient of multiple determination and is a measure of how well the regression fits the data. $sy.x_i$ is the standard error of the estimate.

[2/] The limits on recovery by concentration class for all models are from 0.2 to 4.0 gal/100 ft^2.

APPENDIX II

Algebraic Models

ALGEBRAIC MODELS FOR RETARDANT RECOVERED AS A FUNCTION OF CONCENTRATION (DISTRIBUTION) AND DROP HEIGHT FOR 700-GALLON DROPS OF EACH RETARDANT

```
      AB = EXP(-(ABS((((XLEN - DH)/XP)-1.0)/(1.0-XI))**XN))
      AC = EXP(-(ABS(1.0/(1.0-XI))**XN ))
      A(N,M) = B * YP * (AB-AC)/(1.0-AC)
      XCONC = 4.0 - CONC
      Z = CONC/4.0 - 1.0
      ZZ = XCONC/4.0 - 1.0
      ZY = XCONC/3.8 - 1.0


PHOS-CHEK XA 700  DIST
      B = .9886083452
      XLEN = 5000.0
      XP   = 5000.0
      YP = 59.1 + 19.7 * EXP(-(ABS(ZY/.32)**2.3)) - 20.9 * EXP(-(ABS(Z/.
     135)**3.0))
      XI = .935 - .03 * XCONC - .785 * EXP(-(ABS(ZZ/.19)**1.85))
      XN = 1.50 - .04 * XCONC + .45 * EXP(-(ABS(ZY/.182)**2.0))


GELGARD 700     DIST
      B  = .988113
      XLEN = 5000.0
      XP = 5000.0
      YP = 37.7 + 39.1 * (EXP(-(ABS(ZY/.605)**1.3))-.1463369)/.8536631
      XI = .83 - .75 * EXP(-(ABS(ZY/.137)**1.3)) + .119 * EXP(-(ABS(Z/.3
     195)**4.0))
      XN = 1.50 + .40 * EXP(-(ABS(Z/.29)**3.0))


FIRE-TROL 100  700  DIST
      B  = .965055
      XLEN = 4000.0
      XP = 4000.0
      YP = 22.5 + 8.10848 * XCONC**1.44 - 8.34 * (EXP(-(ABS(ZY/.268)**1.
     15))-.00074085)/.99925915
      XI = .910 -.210 * EXP(-(ABS(ZY/.183)**1.6))
      XN = 1.70 - .25 * EXP(-(ABS(ZY/.32)**5.0))


WATER 700       DIST
      B  = .9790687059
      XLEN = 3500.0
      XP = 3500.0
      YP = 44.0 + .1017158571 * XCONC**4.2 - 17.4 * EXP(-(ABS(Z/.35)**4.
     15))
      XI = .92 - .01 * XCONC - .182 * EXP(-(ABS(ZY/.20)**2.0))
      XN = 2.80 - 1.32 * EXP(-(ABS(ZY/.224)**2.2)) - .60 * EXP(-(ABS(Z/.
     128)**3.0))
```

```
      AB = EXP(-(ABS((((XLEN - DH)/XP)-1.0)/(1.0-XI))**XN))
      AC = EXP(-(ABS(1.0/(1.0-XI))**XN ))
      A(N,M) = B * YP * (AB-AC)/(1.0-AC)
      XCONC = 4.0 - CONC
      Z = CONC/4.0 - 1.0
      ZZ = XCONC/4.0 - 1.0
      ZY = XCONC/3.8 - 1.0


PHOS-CHEK XA 1400 DIST
      B  = .9898195490
      XLEN = 6000.0
      XP = 6000.0
      YP = 64.9 + 5.524582204 * XCONC**.82 + 4.89176 * EXP(-(ABS(ZZ/.135
     1)**1.5))
      XI = .915 - .04010705929 * XCONC**1.64 - .486849 * EXP(-(ABS(ZY/.1
     193)**1.8))
      XN = 1.45 + .55 * (EXP(-(ABS(((XCONC/3)-1.0)/.43)**2.0))-.004791)/
     1.995521 - 2.7284811E-13 * XCONC**20


GELGARD 1400     DIST
      B  = .967540
      XLEN = 5000.0
      XP = 5000.0
      YP = 47.0 + 5.6 * XCONC  +  .94 * (EXP(-(ABS((CONC(N)-1.0)/.999)**
     112.5))-.363278)/.636721
      XI = .740 - .66 * EXP(-(ABS(ZY/.22)**2.0)) + .187 * EXP(-(ABS(Z/.3
     12)**4.0))
      XN = 1.28 + .72 * EXP(-(ABS(Z/.20)**2.0)) + .22 * EXP(-(ABS(ZY/.15
     15)**2.0))



FIRE-TROL 100  1400 DIST
      B  = .9802734525
      XLEN = 4000.0
      XP = 4000.0
      YP = 36.2 + 7.8184774 * XCONC**1.195
      XI = .42 + .3204384752 * CONC(N)**.38 - .00057848 * CONC(N)**3.4
      XN = 1.44 + .72 * (EXP(-(ABS(((CONC(N)/2.45)-1.0)/.9)**2.1))-.2871
     1805585)/.7128194414



WATER 1400       DIST
      B  = .9897637968
      XLEN = 4000.0
      XP = 4000.0
      YP = 38.6 + 7.915588013 * XCONC**1.33 - 7.52955 * EXP(-(ABS(ZY/.3)
     1**3.0))
      XI = .9457317537 * CONC(N)**.144 - .2 - .0547 * EXP(-(ABS(Z/.265)*
     1*2.4))
      XN = 1.45 + 2.15 * (EXP(-(ABS(((CONC(N)/3.3)-1.0)/.45)**1.4))-.046
     1960065l2)/.9530399348
```

ALGEBRAIC MODELS FOR AREA OF COVERAGE BY DROP HEIGHT AND CONCENTRATION CLASS FOR 700-GALLON DROPS OF EACH RETARDANT

```
      AB = EXP(-(ABS((((XLEN - DH)/XP)-1.0)/(1.0-XI))**XN))
      AC = EXP(-(ABS(1.0/(1.0-XI))**XN ))
      A(N,M) = B * YP * (AB-AC)/(1.0-AC)
      XCONC = 4.0 - CONC
      Z = CONC/4.0 - 1.0
      ZZ = XCONC/4.0 - 1.0
      ZY = XCONC/3.8 - 1.0


PHOS-CHEK XA 700  AREA
      B  = .9008551070
      XLEN = 6000.0
      XP = 6000.0 - 1425.0 * (EXP(-(ABS(ZZ/.35)**1.3))-.019942)/.9800558
     1157
      YP = 3650.0 + 1628.0 * XCONC**1.87 + 2.99705 * XCONC**7.0
      XI = .940 - .0214 * XCONC**2.05
      XN = 2.80 - .1715 * ABS(CONC(N)-2.0)**2.5


GELGARD 700      AREA
      B  = .9942035
      XLEN = 4000.0
      XN = 3.0
      XP = 2600.0 + 1400.0 * (EXP(-(ABS((((CONC(N)-.2)/3.8)-1.0)/.8)**3.
     10)) - .14183)/.85817
      YP = 4100.0 + 1150.0 * XCONC**2.0 + 29394.0 * EXP(-(ABS(ZY/.169)**
     12.0))
      XI = .59 + .345 * (EXP(-(ABS((((CONC(N)-.2)/3.8)-1.0)/.55)**3.2))-
     1.00114)/.99886 - .32 * EXP(-(ABS(ZY/.08)**1.2))


FIRE-TROL 100  700  AREA
      B = .9782396595
      XLEN = 6000.0
      YP = 2400.0 + 1557* XCONC**1.89 + 36808.0 * EXP(-(ABS(ZZ/.106)**2.
     10))
      XP = 6000.0
      XI = .886 + .018 * CONC(N) - .13 * (EXP(-(ABS((((2.0 -CONC(N))/1.8
     1)-1.0)/.51)**2.0)) - .021393 ) / .978607
      XN = 1.79 + .71 * EXP(-(ABS(((XCONC/3.0)-1.0) / .24)**5.0))


WATER  700      AREA
      B  = 1.010916634
      XLEN = 5000.0
      XP = 5000.0 - 1100.0 * EXP(-(ABS(ZZ/.057)**6.0))
      YP = 891.823385 * XCONC**2.35 + 2410.0 + 27242.0 * EXP(-(ABS(ZY/.1
     1)**2.0))
      XI = .775 + .149 * (EXP(-(ABS(((CONC(N)/3.0)-1.0)/.76)**3.6))-.068
     11677)/.9318322 + .0240196 * (EXP(-(ABS(Z/.15)**6))-.0012726)/.9987
     2273
      XN = 2.8 + 1.1772549 * XCONC**.25 - 2.493676 * EXP(-(ABS(ZY/.268)*
     1*3.07))
```

```
      AB = EXP(-(ABS((((XLEN - DH)/XP)-1.0)/(1.0-XI)))**XN))
      AC = EXP(-(ABS(1.0/(1.0-XI)))**XN ))
      A(N,M) = B * YP * (AB-AC)/(1.0-AC)
      XCONC = 4.0 - CONC
      Z = CONC/4.0 - 1.0
      ZZ = XCONC/4.0 - 1.0
      ZY = XCONC/3.8 - 1.0


PHOS-CHEK XA 1400 AREA
      B  = .954253667
      XLEN = 6000.0
      XI = .895 - .355  *     (EXP(-(ABS(((XCONC/3.0)-1.0)/.3)**1.1))-.02
     1328801931)/.9767119806 - .406476 * EXP(-(ABS(ZY/.12)**3.0))
      YP = 8000.0 + 5368.035 * XCONC**1.62 + 31427.0 * EXP(-(ABS(ZY/.25)
     1**3.0))
      XP = 3940.0 + 1860.0 * (EXP(-(ABS(Z/.697)**3.0))-.05216936253)/.94
     178306374
      XN = 2.08 - .18 * EXP(-(ABS(ZY/.31)**3.0)) + .57 * EXP(-(ABS(Z/.10
     16)**1.4))


GELGARD 1400     AREA
      B  = .998498
      XLEN = 4500.0
      XP = 4400.0 - 252.27 * XCONC**1.25 - 412.0 * EXP(-(ABS(ZY/.212)**2
     1.2))
      XI = 1.084 - .15139 * XCONC**1.26 - .194 * EXP(-(ABS(Z/.22)**2.0))
     1 - 8.325E-16 * XCONC**25
      XN = 2.2 + .84 *(EXP(-(ABS(Z/.57)**2.5))-.01696)/.98304 + 2.7907E-
     113 * XCONC**20
      YP = 6000.0 + 2704.8 * XCONC**2.33 + .0038114 * XCONC**11.95


FIRE-TROL 100  1400 AREA
      B  = .9402160937
      XLEN = 6000.0
      XP = 6000.0 - 2000.0 * EXP(-(ABS(ZY/.19)**2.0))
      YP = 6820.0 + 3624.84 * XCONC**1.32 + 54265.0 * EXP(-(ABS(ZY/.16)*
     1*2.0))
      XI = .83 + .09 * (EXP(-(ABS(Z/.5)**3.0))-.00033546)/.9996453 - .75
     1406432 * EXP(-(ABS(ZY/.15)**4.0))
      XN = 1.8 + .7985346 * XCONC**.81 -  2.1546 * EXP(-(ABS(ZY/.265)**2
     1.0))


WATER 1400       AREA
      B  = .9875917747
      XLEN = 5000.0
      XP = 5000.0 - 17.76230351 * XCONC**3.2
      YP = .1841706523 * XCONC**9.58 + 7370.0 + 4631.352384 * XCONC**1.1
     185
      XI = .915 - .01793504977 * XCONC**1.45 - .1907235607 * EXP(-(ABS(Z
     1Y/.219)**2.5))
      XN = 2.2475 + .0125 * CONC(N) + 1.015 * EXP(-(ABS(((CONC(N)/3.0)-1
     1.0)/.408)**3.6)) + 1.076 * EXP(-(ABS(Z/.069)**1.5))
```

ALGEBRAIC MODELS FOR CONTOUR LENGTHS BY DROP HEIGHT AND CONCENTRATION CLASS
FOR 700-GALLON DROPS OF EACH RETARDANT

```
      AB = EXP(-(ABS((((XLEN - DH)/XP)-1.0)/(1.0-XI))**XN))
      AC = EXP(-(ABS(1.0/(1.0-XI))**XN ))
      A(N,M) = B * YP * (AB-AC)/(1.0-AC)
      XCONC = 4.0 - CONC
      Z = CONC/4.0 - 1.0
      ZZ = XCONC/4.0 - 1.0
      ZY = XCONC/3.8 - 1.0


PHOS-CHEK XA  700  LENGTH
      B  =.9503484734
      XLEN = 4000.0
      XI = .88 - .127 * (EXP(-(ABS(((XCONC/3.0)-1.0)/.7)**2))-.129922608
     13 / .8700773916 - .3227176356 * EXP(-(ABS(ZY/.12))**3.5))
      XN = 1.9 - .5 * XCONC**2 + 4.7263 * EXP(-(ABS(ZY/.57)**6)) - 6.762
     16E-4 * XCONC**5 + 4.721521872 * EXP(-(ABS(ZY/.1)**3)) - 1.1 * EXP(
     2-(ABS(((XCONC/2.5)-1.0)/.1)**20))
      XP = 4000.0 - 1050.0 * EXP(-(ABS(ZY/.2)**2))
      YP = 133.0 + 63.91275992 * XCONC**1.1 + 84.4446977 * EXP(-(ABS(ZY/
     1.15)**1.5))


GELGARD 700   LENGTH
      B  = .9813159087
      XLEN = 4000
      XI = .91 - .90 * (EXP(-(ABS(ZY/.5)**3.0))-.00033546)/.99968454
      XN = .881807 * XCONC**.75 + 2.55 * EXP(-(ABS(Z/.37)**6))
      XP = 4000.0 - 1000.0 * EXP(-(ABS(ZY/.31)**4.0))
      YP = 125.0 + 22.11807424 * XCONC**2.1


FIRE-TROL 100 700  LENGTH
      B = 1.017243819
      XLEN = 4000.0
      XI = .715 + .200 * EXP(-(ABS(Z/.76)**6.0))
      YP = 152.0 + 38.53159496 * XCONC**1.2 + 2.911623174E-10 * XCONC**
     120
      XN = 1.45 + .040 * XCONC + .43 * EXP(-(ABS(ZZ/.086)**3.0))
      XP = 4000.0 - 590.0 * EXP(-(ABS(ZZ/.169)**1.48 ))


WATER 700 LENGTH
      B = .9818835078
      XP = 4000.0
      XLEN = 4000.0
     1-.00028493)/ .999715
      XI = .32 + .46785 * CONC(N)**.31 - .122 * (EXP(-(ABS(Z/.35)**2.0))
      XN = .725 * CONC(N) + .81333 - 1.37634E-12 * CONC(N)**20 +
     18.623725436E-13 * XCONC**21
      YP = 94.0 + 53.994 *  XCONC**1.15 + 2.647005328E-10 * XCONC**20
```

ALGEBRAIC MODELS FOR CONTOUR LENGTHS BY DROP HEIGHT AND CONCENTRATION CLASS
FOR 1,400-GALLON DROPS OF EACH RETARDANT

```
      AB = EXP(-(ABS((((XLEN - DH)/XP)-1.0)/(1.0-XI))**XN))
      AC = EXP(-(ABS(1.0/(1.0-XI)))**XN ))
      A(N,M) = B * YP * (AB-AC)/(1.0-AC)
      XCONC = 4.0 - CONC
      Z = CONC/4.0 - 1.0
      ZZ = XCONC/4.0 - 1.0
      ZY = XCONC/3.8 - 1.0


PHOS-CHEX XA  1400 LENGTH
      B = .97150
      XLEN = 5000.0
      XI = .5 + .33 * EXP(-(ABS( Z/.376)**4.4))
      XN = .9 + 2.0  * (EXP(-(ABS((CONC(N)/3.0-1.0)/.82)**1.36))-.269867
     1)/.730133 + 1.008 * EXP(-(ABS(ZY/.1)**2.3))
      YP = 164.0 + 57.7263 * XCONC**1.45
      XP = 4000.0 + 700.0 * EXP(-(ABS(Z/.42)**3.7)) + 300.0 * (EXP(-(ABS
     1((CONC(N)-1.0)/.58)**3.9))-2.3214E-4)/.999768


GELGARD 1400 LENGTH
      B  = .9860537701
      XLEN = 4000.0
      XI = .84 - .83 * (EXP(-(ABS(ZY/.47)**2.5))-.001356)/.998644
      XN = 1.8 + 2.1 * XCONC - 6.00 * EXP(-(ABS(((XCONC/3.0)-1.0)/.41)**
     13.0)) - 2.8232 * EXP(-(ABS(ZY/.085)**3.0))
      XP = 4000.0 - 1000.0 * EXP(-(ABS(ZY/.39)**2.5))
      YP = 140.0 + 11.93626796 * XCONC**3.4 - 767.2047881 * EXP(-(ABS(ZY
     1/.216)**1.6))  + 80.0 * EXP(-(ABS(((CONC(N)/.5)-1.0)/.3)**8))


FIRE-TROL 100 1400 LENGTH
      B  = .8803827977
      XLEN = 4000.0
      XI = .83 - .18 * EXP(-(ABS(((XCONC/3)-1.0)/.47)**4.0)) - .16271933
     162 * EXP(-(ABS(ZY/.1)**3.0))
      XN = 3.0 + .80 * XCONC - 3.9 * EXP(-(ABS(((XCONC/3.0)-1.0)/.48)**4
     1.0)) - .794 * EXP(-(ABS(ZY/.085)**3.0)) +.344 * EXP(-(ABS(((CONC(N
     2)/1.5)-1.0)/.2)**9.0))
      XP = 4000.0 - 300.0 * EXP(-(ABS(ZY/.24)**3.0))
      YP = 145.0 + 379.0  * (EXP(-(ABS(ZY/.6)**1.1))-.1730/7415)/.826922
     15849


WATER  1400  LENGTH
      B  = 1.0
      XLEN = 4000.0
      YP = 145.0 + 102.4530192 * XCONC**.55 + .0023685571 * XCONC**8.2
      XI = .87 *(EXP(-(ABS(((CONC(N)/3.0)-1.0)/.9)**3.0))-.253664662)
     1/ .7463353379 + 3.515183925E-11  * CONC(N)**15
      XN = 1.7 + 3.7004798E-5 * CONC(N)**7.2 + 4.0592710J4E-12*XCONC**20
      XP = 4000.0 - 1000.0 * (EXP(-(ABS(ZY/.1))**1.5))
```

GEORGE, CHARLES W.

1975. Fire retardant ground distribution patterns from the CL-215 air tanker. USDA For. Serv. Res. Pap. INT-165, 67 p., illus. (Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.)

Several fire retardants in current use were dropped from the Canadair CL-215 aircraft to determine drop height effects and for evaluation of the tank and gating system. Mathematical models for each retardant and load size were developed for predicting the effects of drop height on ground distribution as shown by the retardant recovery, area of coverage, and contour (fireline) length as functions of concentration level.

OXFORD: 432.3: 843.1. KEYWORDS: aerial fire suppression, fire-retardant chemicals, models, predictions, ground distribution patterns, drop heights, air tankers.

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PREDICTING EFFECTS ON FISH OF FIRE RETARDANTS IN STREAMS

Wayne P. Van Meter and
Charles E. Hardy

USDA Forest Service
Research Paper INT-100
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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401
Roger R. Bay, Director

THE AUTHORS

WAYNE P. VAN METER has been a faculty member of the University of Montana, Department of Chemistry, since 1959. He also conducts occasional summer research studies for the Fire Technology research work unit at the Northern Forest Fire Laboratory in Missoula. He received his B.S. and M.S. degrees from Oregon State University and his Ph.D. degree in chemistry from the University of Washington in 1959.

CHARLES E. HARDY joined the Northern Rocky Mountain Forest and Range Experiment Station, Division of Fire Research, in 1951. He has conducted studies relating to fire-danger rating, prescribed fire, fire behavior, Alaskan fire problems, and fire retardant chemicals. He received his B.S.F. degree from the University of Montana in 1939 and his M.F. degree from the University of Michigan in 1949. He served on the staffs of two National Forests and the Division of Fire Control in the Forest Service's Northern Region. At the time of his retirement in December 1973, Mr. Hardy was leader of the Fire Technology research work unit. Currently, he is a Fire Research Consultant.

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ABSTRACT

Reports a first attempt to provide a computation system that will permit a rapid estimate of the amount of hazard to game fish caused by release of fire retardant chemical into streams. Field measurements necessary for application of the system are (1) the amount of retardant (pounds, nitrogen, calculated as NH_3) that enters a stream and (2) the discharge rate and average velocity of the stream, both measured at or near the point of retardant introduction. The result is an estimate of the time, or distance, necessary to allow dilution of the pollutant by shear and turbulent mixing to produce nonlethal conditions. Accuracy expected is about plus or minus 75 percent of the result. Despite a large uncertainty, the estimate is valuable and useful. Causes of this uncertainty are discussed and sample computations are presented using U.S. Geological Survey data for several western Montana streams.

INTRODUCTION

In recent years, fire retardant materials applied by aircraft have become important in the control of range and forest fires. The number of fire retardant drop missions flown rose from virtually zero in the mid-1950's to nearly 15,000 in 1971 and involved some 17 million gallons of material (assuming an average drop of 1,100 gallons). Use of sodium calcium borate was discontinued in the early 1960's because it was heavy, expensive, and a soil sterilant. More effective retardant salts, ammonium phosphates and sulfates, have been used for more than a decade. In general, they are fertilizers and produce beneficial results unless a dosage is too heavy.

Wildfires may occur in areas where lakes and flowing streams contain valuable game fish. Fire retardants are concentrated aqueous solutions of chemical materials. Since at some concentration, most soluble chemicals will injure or kill fish, the possibility of damage to fish exists because retardants can be dropped directly into the body of water in which they live.

The purpose of this report is to provide a method of estimating whether fish kill is likely to result from a particular release of retardant. The approximate length of the affected zone of a stream can be calculated. Accuracy of the result is expected to range between plus or minus 75 percent, which is not precise, but can be of considerable value. This figure is the result of estimating the probable uncertainty of each item or source of data required for a computation, and then tracing the cumulative effect of these uncertainty values through the computation procedure outlined in this report. Where two or more values are combined or interact arithmetically, the uncertainty of the result is identified by finding the square root of the sum of the squares of the individual uncertainties of the values being combined.

It would be important to know, for example, whether a given event would be likely to damage only a few hundred feet of a stream or its length to the next major confluence. The estimation system would make possible a judgment before the drop mission is ordered as to whether the immediate fire control need is great enough to warrant possible consequences. Preseason determination of stream discharge rates and velocities would make potential damage appraisal a simple matter.

There are two main reasons for the low level of accuracy: (1) studies using fire retardant materials approved by the USDA Forest Service show that the toxicity of the neutral ammonia molecule is related to the species and age of the fish and to a variety of such minor constituents of commercial retardant preparations as corrosion and spoilage inhibitors and thickeners and (2) extensive, careful data on the flow characteristics of the stream will not be available.

Many stream gaging stations are maintained by various agencies, and readings are taken daily at some. However, only a few streams--perhaps a hundred or so in the whole United States--have been studied by using dye tracers to allow calculation of the discharge rate and mean velocity at any desired point from data collected routinely at an index gage station. Thus, a field approximation of flow characteristics will generally have to suffice. Also, at this point, we can only assume that the diffusion characteristics of fire retardant solutions or slurries are similar to those of dyes used in the referenced experiments. We have not explored the possibility of significant differences.

Most fire retardants now in use contain diammonium phosphate ($(NH_4)_2HPO_4$), monoammonium phosphate ($NH_4H_2PO_4$), ammonium polyphosphate or ammonium sulfate ($(NH_4)_2SO_4$) as the active ingredient. Other components provide thickening, inhibit bacterial spoilage, control corrosion of aircraft structures, and provide color for visibility. Of these substances, the one that is the limiting factor for fish poisoning is the ammonium portion of the active fire retardant material (McKee and Wolf 1963). Therefore, calculations described are based on the number of pounds of nitrogen placed into the water, calculated as pounds of ammonia, NH_3. The neutral, molecular form of ammonia, NH_3, is the active entity. The acidity of the solution (pH) controls the balance of the ammonia between NH_3 and the ammonium ion, NH_4^+. Allowance for this factor is made in the computation procedure.

PREVIOUS STUDIES

A few streams have been studied in detail in a way that has provided a method of predicting the behavior of contaminants. The Monocacy River in Maryland is a prime example of such a study (Taylor 1970). The probable use for this kind of a stream analysis system is related to the use of stream water for municipal supplies. If, for example, a truckload of soluble contaminant is spilled into the stream, both the time of arrival and the duration of contamination at the system intake can be predicted. As applied to fire retardant operations, the system will allow prediction of the time and distance a contaminant must travel to be sufficiently diluted to avoid fish fatalities.

The stream analysis employed by Taylor on the Monocacy River involved the introduction at one point in the stream of a soluble "slug" of fluorescent dye. At each of several downstream locations, measurements were made of (1) dye concentration at appropriately spaced times (15 minutes to several hours) and (2) stream discharge, as measured by a current meter.

The discharge rate was also monitored continuously at some one index gaging point to permit corrections for changes during the experiment. These measurements permit calculation of the discharge rate, Q, and the mean velocity, v. The discharge rate is the number of cubic feet per second of water flowing past a point, or through an imaginary plane perpendicular to the direction of flow. The mean velocity equals the discharge rate Q divided by the area in square feet of the cross section of the stream (the area of the plane between water surface and streambed).

In reducing the data to useful form, the concentrations at each sampling point were plotted against time. Plotting produced a graph that rises rapidly to a rounded peak, then decreases with some tailing toward zero. By using the known Q for that sampling point and the integrated area under the curve, the quantity of dye passing that point was calculated. Some loss occurred from adsorption on streambed material and vegetation, from chemical change of the dye, and perhaps from other more obscure causes. If the original amount of dye introduced is known, it is possible to correct for this loss by increasing the observed concentrations to represent a totally conservative dye. A conservative solute would be the idealized case where no dye is lost to solid surfaces over which the solution flows.

Numerous tests on the same stream conducted at different discharges and with different quantities of dye are not readily comparable as both factors determine the magnitutude of observed dye concentrations. A method developed by the U.S. Geological Survey (Kilpatrick and others 1970) provides a means of comparing and analyzing dispersion effects existing for different streams. In the Monocacy River study, Kilpatrick developed and Taylor used the concept of unit concentration, particularly as applied to maximum concentration peaks. Unit concentration, C_u, was computed for each sampling point according to:

$$C_u = (\text{conservative concentration, mg/l}) \frac{(Q, \text{cfs})}{(\text{amount introduced in lb})} \qquad (1)$$

The concentration and the discharge rate were those measured at a given sampling point at the same time. The original amount introduced was the same for all sampling points and all times.

The time required for the concentration peak to reach any particular sampling point, measured from the instant that dye was introduced, was called the lapsed time, T_L. It was determined by noting the position of the peak-concentration-versus-time graph for each sampling point.

A graph of C_u versus T_L has the general appearance of figure 1, being approximately parallel to the lines shown. For any one stream, the position of the line is a function of the longitudinal dispersion, which is logarithmically related to the discharge rate and, therefore, to the mean velocity. Comparison of different streams showed that where $\bar{v}$ is relatively small (mixing is relatively good) the C_u versus T_L line has a steep slope (fig. 1). The slope chosen was thus conservative, implying that concentration will be decreased at least to the indicated value or further.

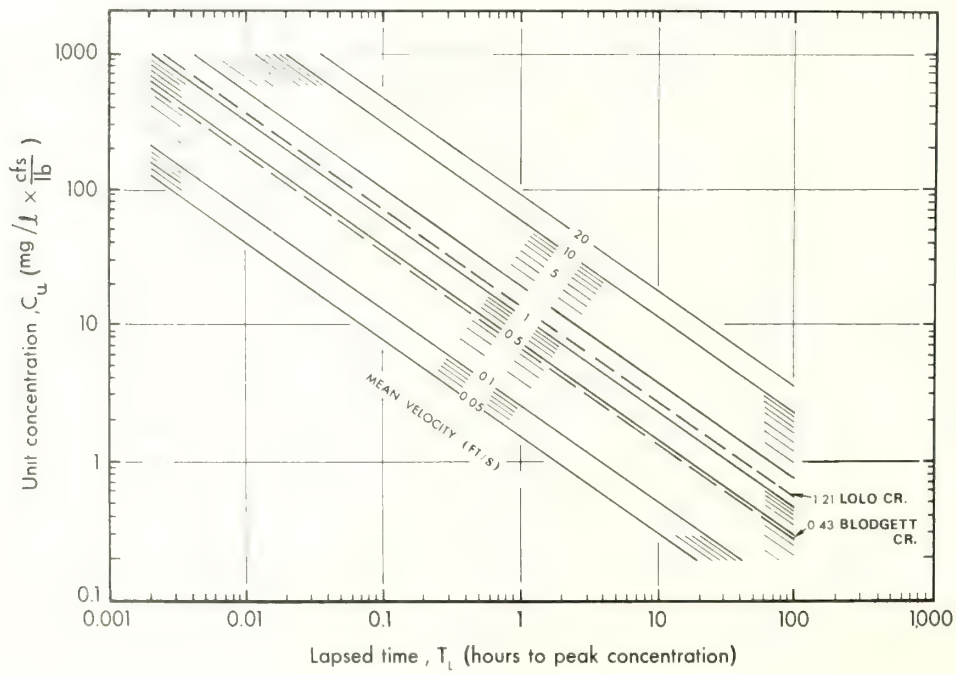


Figure 1.--Unit concentration curves describe the interaction of stream discharge rate and average stream velocity in decreasing peak concentration of the introduced contaminant with time. Curves apply only after complete lateral and vertical mixing.

DISPERSION OF SOLUBLE MATERIALS IN STREAMS

The diluting effect we are interested in depends on the mixing that moves contaminants laterally (across the stream) and vertically, as well as longitudinally (elongating in downstream direction), into volumes of uncontaminated water. Generally, the greater the mean velocity of a stream, the less will be the longitudinal mixing per unit of distance traveled. There are exceptions, since stream geometry also is a factor in determining longitudinal dispersion. A lower velocity will permit turbulent eddies to have a greater effect on the concentration of the contaminant. Lateral and vertical mixing are reached quickly in a stream, but longitudinal mixing (dispersion) continues as long as there is a stream. Always, there will be a gradient of velocity from the line of maximum velocity (just below the surface near channel center) to the line of minimum velocity at bank or bottom surfaces. This gradient causes a shearing phenomenon that contributes largely to longitudinal mixing. Volumes at the channel center move ahead of volumes nearer the banks and bottom.

When a flowing stream acts on a slug of soluble contaminant, the general pattern of events will fit somewhere along a spectrum of possibilities.

If the stream is very large, and the quantity of contaminant not too large, the material will be diluted to harmless levels relatively quickly. If the stream is reasonably large, some zone of probable fish fatalities may exist, but the dilution will occur soon and the contaminated volume will still be small; so exposure time at any point will be short. This means that fairly high concentrations can be tolerated by fish. If the stream is small, dye concentration will remain high for longer distances or times; consequently, the peak will be more spread out, and exposure times longer. Because of this, dilution must continue over greater distances before the combination of concentration and exposure time become tolerable to fish. If the stream is quite small, intolerable conditions may prevail until tributaries significantly add to the discharge and provide the needed dilution.

APPLICATION TO RETARDANT OPERATIONS

In figure 1, the location of a working line for any given stream has been related for utility purposes to the mean velocity rather than to the discharge rate. This approach seems to agree with available data (Taylor 1970) and is more directly associated with the mixing phenomenon. Also, for practical purposes, $\bar{v}$ entails a much smaller range of values than Q (0 to about 5 or 10 feet per second compared to 0 to about 50,000 cubic feet per second).

In addition to the C_u working lines of figure 1, three other graphs are needed. The first (fig. 2) provides knowledge of the length of time that fish will be exposed to the contaminant (exposure time (T_E) as a function of the lapsed time). Taylor's work on the Monocacy River was concerned with the interval during which the concentration might be high enough to represent an appreciable hazard to a drinking water supply. His arbitrary definition of the trailing edge of a peak was that point at which the concentration is 5 percent of the maximum concentration. As a premise for relating the calculating system to the survival of fish experiencing a slug of contaminant, it is reasonable to assume that if a particular fish makes it through the peak concentration, it is then likely to survive the whole event. Thus, an arbitrary choice has been made: exposure time is the length of time that the concentration of contaminant exceeds 50 percent of the peak concentration. Figure 2 is derived from this criterion as applied to time-concentration curves from the Monocacy River study (Taylor 1970).

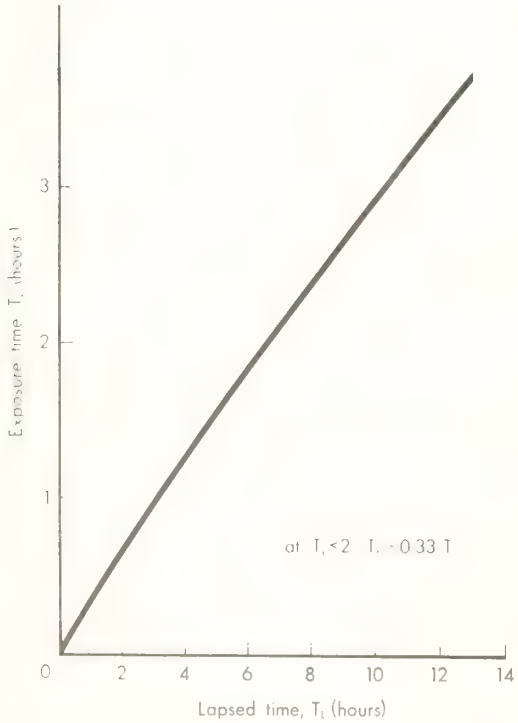


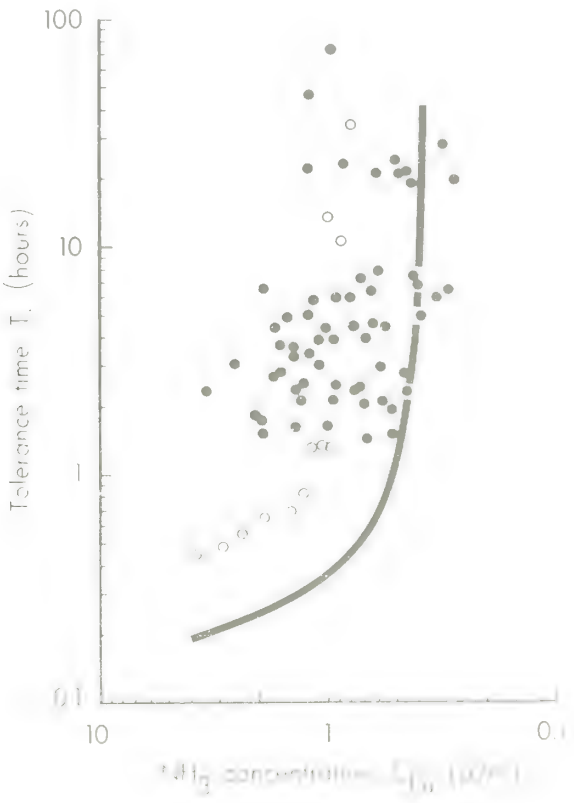
Figure 2.--Variation of length of exposure with time, following introduction of contaminant into stream. Exposure time is that period during which concentration is equal to or greater than 50 percent of the peak concentration at points fixed with respect to the terrain.

By this definition, exposure time is zero at the point where the [illegible] introduced. This definition cannot correctly describe the true situation because at the instant of application, a retardant dispersal pattern will contaminate the surface of perhaps several hundred feet of the stream. Thus, if vertical mixing occurs before the streamflow has moved the pattern very far, the exposure time could be larger temporarily than the corresponding lapsed time. A suitable correction for this effect could be made by using as a total exposure time the sum of the value obtained from figure 2 and the time required for the water to move a distance equal to the length of the original contamination zone. For the examples cited in this report, and probably for most other conceivable circumstances, use of this correction does not change the nature of decisions that might be reached concerning fire retardant operations.

During the time of exposure, T_E, concentration of the contaminent is not constant, but increases to a peak and then decreases. The best value of concentration to use in determining the tolerance time, T_T, is the integrated average concentration over the exposure interval. Using the areas above half-height (50 percent of peak concentration) of the conservative time-concentration curves of the Monocacy River study, the effective concentration, C_E, of the contaminant was found to be 0.83 times the peak concentration.

The next graph needed is one relating contaminant concentrations to the time, T_T, necessary for fatality to occur (fig. 3 or 4). The data of Blahm and others (1972) and of Herbert and Shurben (1964) have been used to determine what this graph should be like. Earlier data exists (McKee and Wolf 1963, p. 134), but few if any workers recorded the pH existing during their experiments.

In figures 3 and 4, the circled points are data from experiments using fingerling rainbow trout (hatchery-reared, Herts., England) and an added chemical, ammonium chloride. The pH was controlled at 7.8 by equilibrating the solution with prepared mixtures of air and carbon dioxide. The solid points are data from experiments using subyearling



ammonia to fish at the 10 percent mor- [illegible] is the concentration of nonionized ammonia, NH_3. Circled points are data of Herbert and Shurben (1964); solid points are data of Blahm and others (1973).

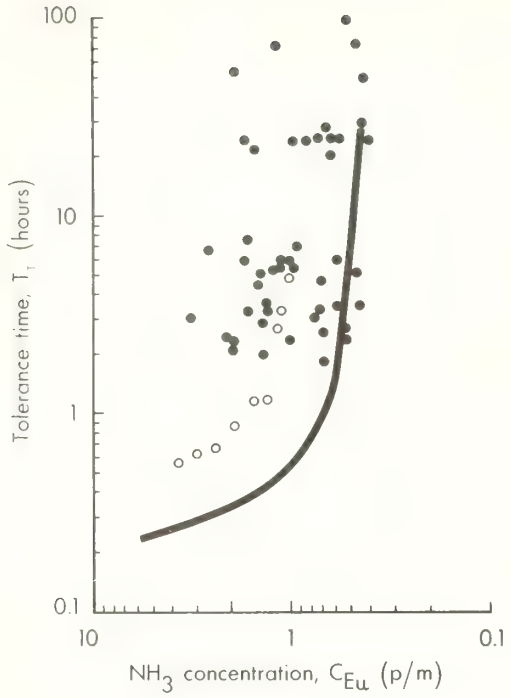


Figure 4.--Toxicity of ammonia to fish at the 50 percent mortality level. C_{Eu} is the concentration of nonionized ammonia, NH_3. Circled points are data of Herbert and Shurben (1964); solid points are data of Blahm and others (1972).

and yearling specimens of both rainbow trout and the coho salmon (hatchery-reared, Oregon). These fish were subjected to various concentrations of each of four different commercial fire retardant preparations. The pH of the solutions was not controlled, but it was measured during each experiment. For each data point in figures 3 and 4, the total concentration of ammonium compound(s) and the pH have been used to calculate the concentration of molecular (nonionized) NH_3.

The curvature of the graph at higher concentrations and lower times is certainly real. It is likely, though, that if Herbert and Shurben (1964) had used more than one species of fish and more than one type of contaminant, a scattering of data similar to that of Blahm and others (1972) would have been produced. Since it is clear that conditions will also fluctuate in field use, working curves in figures 3 and 4 approximate the "safe" edge of point distributions. This is to say that by using the curves, one can predict the worst possible consequence of a given event.

Another graph (fig. 5) facilitates computation of the nonionized NH_3 concentration from knowledge of the total concentrations of NH_3 and NH_4^+ and from the pH. From the ionization constant expression

$$K_b = \frac{[NH_4^+]\ [OH^-]}{[NH_3]} = 1.8\times10^{-5}$$

and the fact that total ammonia nitrogen concentration = $[NH_4^+] + [NH_3]$, it follows that the concentration of nonionized NH_3 (hereafter called C_{Eu}) is

$$C_{Eu} = \frac{\text{(total concentration)}}{1 + K_b/[OH^-]} \qquad (2)$$

The factor $K_b/[OH^-]$ is a simple logarithmic function of pH, and values for it are available from the graph in figure 5.

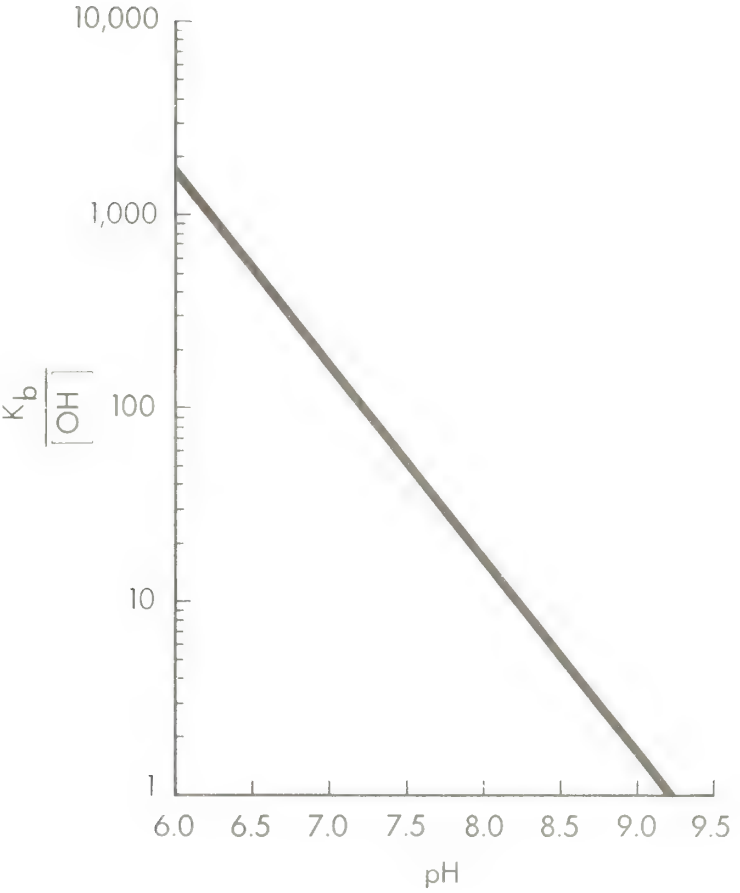


Figure 5.--A graph of the relation between $K_b[OH^-]$ [illegible], where $[OH^-]$ is the molarity of hydroxide ions in the solution and K_b is the ionization constant of ammonia, [illegible].

SAMPLE COMPUTATIONS

The data presented in table 1 are from the files of the United States Geological Survey in Helena, Montana. They represent a range of stream sizes and the usual state of flow conditions during the fire season.

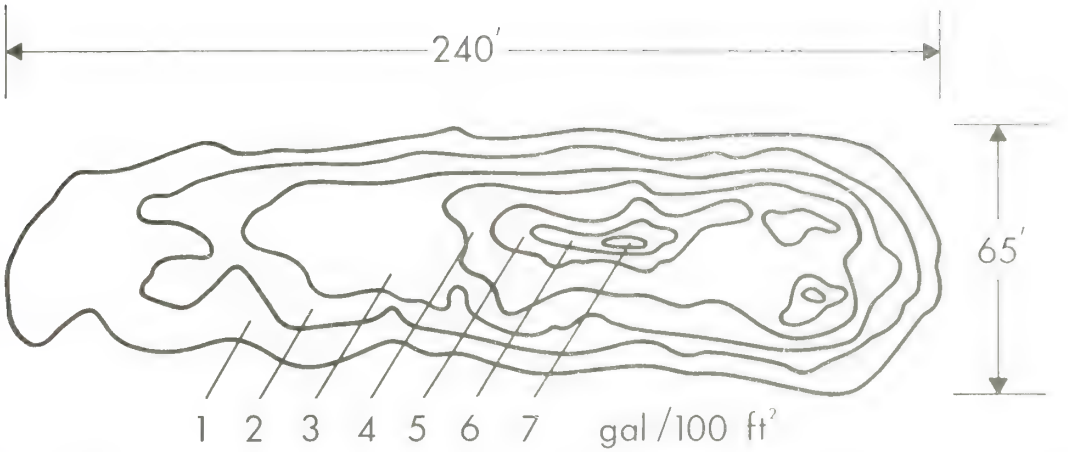
The approximate dimensions of the dispersal pattern produced on the ground by a 600-gallon retardant drop from usual altitudes (100 to 300 feet) have been established (MacPherson 1967). From a representative contour pattern of such a drop and by using the stream width in table 1, estimates can be made of the amount of retardant that might enter the water if the aircraft track is (1) parallel or (2) perpendicular to the stream (fig. 6). Such estimates are made by superimposing the dispersal pattern on a map of the stream. Summation of areas common to the stream and to each contour of retardant density yields the volume of retardant entering the stream. Knowledge of the concentration of total ammonia in the retardant mixture yields the quantity of ammonia that entered the stream.

Table 1.--*Selected data from United States Geological Survey gaging station records*

Station number	Location	Date	$\bar{v}$ [1/]	Q [2/]	Area	Width
			$Ft\ s^{-1}$	$Ft^3\ s^{-1}$	Ft^2	Ft
12-3514	Eightmile Creek (Florence, Mont.)	8/27/63	1.12	4.9	4.35	9
12-3475	Blodgett Creek (Corvallis, Mont.)	8/26/68	.43	11.7	27.2	31
12-3520	Lolo Creek (above Sleeman Creek, Lolo, Mont.)	9/12/60	1.21	35.9	29.6	46
12-3400	Blackfoot River (Bonner, Mont.)	8/27/69	1.88	730.0	389.0	195

1/ Mean velocity

2/ The number of cubic feet per second of water flowing past a point, or through an imaginary plane perpendicular to the direction of flow.



the release of 600 gallons of retardant from an altitude of 100 to 300 feet.

Of course, concentration at the point of contamination is high. If it is great enough to produce a lethal zone, then lethal conditions will prevail only until the dilution has proceeded to a set of conditions we will call "critical." The distance the concentration peak is required to travel to reach that set of conditions is called "the critical distance." Beyond this point fish survival is likely.

The computation process begins with an assumption of the distance a concentration peak will travel downstream from the point of introduction. This assumption should be a first guess of the distance required to dilute the contaminant just to the critical condition. But, it is better to make the first assumed distance too long rather than too short, for several reasons. The process continues by using the assumed distance and the available data for discharge, Q, and the mean velocity, $\bar{v}$, to calculate lapsed time, T_L, and exposure time, T_E. Next, T_L and $\bar{v}$ are used to find the unit concentration, C_u, from figure 1. After estimating the amount of total ammonia that entered stream, C_u and Q can be used in equation (1) to find the conservative concentration, C_D. The effective concentration, C_E, is then 83 percent of C_D. The effective nonionized concentration is calculated from figure 5 and equation (2). The tolerance time, T_T, is then read from figure 3 or 4. T_T will turn out to be approximately equal to T_E when the chosen distance is equal to the critical distance.

The computation steps just described are presented below in their proper order. Their numerical and letter headings correlate with numerical examples and tables in following sections.

1. Acquire values (tabulated data or field measurement) for discharge, Q, mean velocity, $\bar{v}$, and pH.

2. Assume some distance of travel.

3. Compute exposure time, T_E.

   A. From $\bar{v}$ and distance find lapsed time, T_L.

$$T_L = \frac{\text{distance, ft}}{\bar{v}, \text{ ft/s}} \left(\frac{1}{3{,}600 \text{ s/h}} \right) \text{h}$$

B. From T_L and figure 2 find T_E.

4. Compute tolerance time, T_T.

A. From T_L, v, and figure 1 find the unit concentration, C_u.

B. Estimate the amount of NH_3 that entered the stream.

C. From C_u, Q, pounds NH_3, and equation (1), find the conservative concentration, C_p.

D. Compute the effective concentration, C_E.

$$C_E = 0.83\ C_p$$

E. From C_E, figure 5, and equation (2), find the effective nonionized concentration, C_{Eu}.

F. From C_{Eu} and figure 3 or 4, find T_T.

5. Calculate the ratio, T_E/T_T.

Repeat steps 2 through 5, choosing other values of distance, until critical conditions are reached.

If the original choice of distance was too long, then the ratio T_E/T_T will be less than 1.00. Choosing a somewhat shorter distance will produce a ratio closer to or perhaps greater than 1.00. Rather than a large number of repeated computation series, a graphical method of finding the critical distance would be the most efficient.

The example given presents this technique. The appendix shows the results of several computation series based on a hypothetical retardant drop over Lolo Creek with the aircraft track approximately parallel to the stream. The amount of NH_3 entering the stream is estimated at 111 pounds. Hydrologic data are real. If several values of T_E/T_T, bracketing the area where $T_E/T_T = 1.00$, are plotted against distance, as in figure 7, curve a (from 30,000 down to 15,000 feet), the intersection of the curve with the $T_E/T_T = 1.00$ ordinate locates the critical distance. In figure 7, curve b shows the effect of applying the C_{Eu} to the 10 percent mortality data of figure 3.

If further computation steps are carried out for shorter distance choices, the value of the ratio again falls below 1.00. This value could signify an actual zone in which fish would be likely to survive if, but only if, the contaminant were introduced as a very small volume of concentrated solution. Such a situation could produce an exposure time so brief at small lapsed times that the likelihood of survival is significant. However, usually in delivery by air tanker, the exposure time is significant even near the point of delivery. If a zone of lethal conditions exists at all, it probably begins at or very near the delivery point and persists downstream to the critical point.

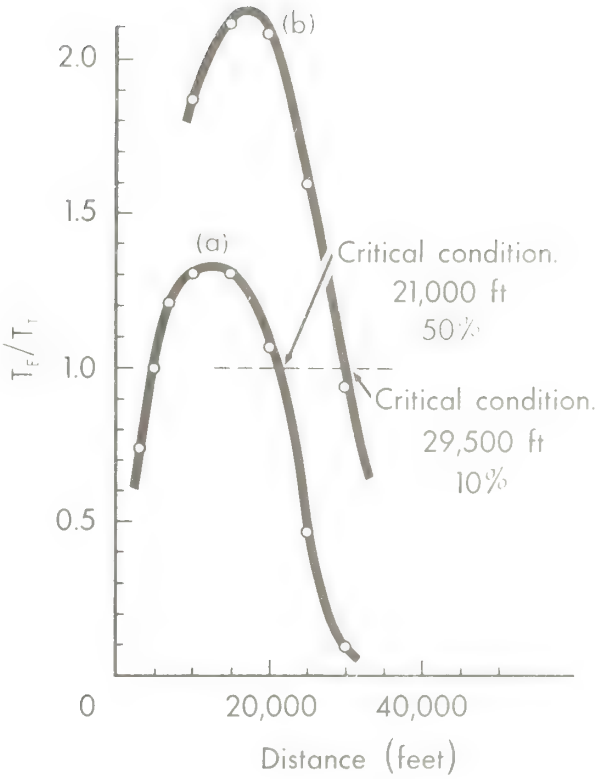


Figure 7.--Ratio of exposure time to tolerance time as a function of distance traveled. A plot of the results of the sample computation using data on Lolo Creek (see appendix).

DISCUSSION

The Western Fisheries Ecology Station, Environmental Protection Agency, Corvallis, Oregon, recently joined with the Forest Service and the Bureau of Land Management in undertaking research to define water quality criteria needed to protect desirable freshwater fishes in the Pacific Northwest. Determination of fish survival in water containing various concentrations of fire retardant formulation is one part of their endeavor. Some early data provided by this effort are, in part, the basis for the toxicity curves in figures 3 and 4 of this report.

Clearly, the field data for a given application of this system are likely to be approximate. Stream conditions could be measured carefully at the introduction point soon after the event, but estimates, such as those for pH and mean annual low discharge values, will be used in many cases. The amount of ammonia involved will be accurately known only if the whole load enters the stream. In most instances, a judgment will hav to be made, based on the overlap of the dispersion pattern intersecting the stream and the size of the aircraft load. Recognition of these factors and collection of the best possible data will be important to any use of the method. The expected accuracy of the estimate, plus or minus 75 percent of the result, reflects consideration of these factors.

The method described in this paper usually will be applied:

1. As a part of fire planning and fire suppression operations. This application allows for a before-the-fact decision as to whether or not to accept the result of knowingly applying retardant across a stream. In a critical firefighting situation, the immediate benefit might be worth it. Discharge rates and cross sections of streams could be predetermined and placed on maps for ready reference. These would be typical low water, fire season values for the streams chosen. The effect of a slug of contaminant at a given point would be calculated and a decision made, based on fishery importance and the fire situation.

2. As an assessment of the effects of an accidental release of fire retardant int a stream. This application would allow calculation of the zone in which damage to fish might be expected. The discharge rate and the cross section of the stream would be measured at or near the point of introduction, if such data were not already tabulated.

Fires can cause fish mortalities by increasing the temperature and ash content of streams and in other ways. This report offers a way of insuring that retardant materials are not blamed for effects they could not have produced.

The computation system described can be applied far more generally than might be apparent from the discussion of its application to fire retardants. It can be used to provide an estimate of the diluting action of a flowing stream on a given amount of any soluble material introduced essentially at one time and at one point on the stream.

LITERATURE CITED

Blahm, T. H., W. C. Marshall, and G. R. Snyder.
1972. Effect of chemical fire retardants on the survival of juvenile salmonids. Nat. Marine Fish. Serv., Prescott, Oreg., 27 p.

Herbert, D. M. W., and D. S. Shurben.
1964. The toxicity to fish of mixtures of poisons. 1. Salts of ammonia and zinc. Annu. Appl. Biol. 53:33-41.

Kilpatrick, F. A., L. A. Martens, and J. F. Wilson, Jr.
1970. Measurement of time of travel and dispersion by dye tracing. *In* Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 3, Chap. A9, p. 25.

McKee, J., and H. Wolf, Eds.
1963. Water quality criteria. Ed. 2, State Calif. Resour. Div. Publ. 3-A.

MacPherson, J. E.
1967. Ground distribution contour measurements for five fire bombers currently used in Canada. Nat. Aeronaut. Estab., Nat. Res. Counc. Can., Aeronaut. Rep. LR-493.

Taylor, K. R.
1970. Traveltime and concentration attenuation of a soluble dye in the Monocacy River, Maryland. Md. Geol. Surv. Inf. Circ. 9, 23 p.

ADDITIONAL REFERENCES

Buchanan, T. J.
1964. Time of travel of soluble contaminants in streams. J. Sanit. Eng. Div. Pap. 3932. 6:1-12.

Dunn, B.
1970. Time of travel studies in the Fall Creek Basin, Tompkins County, New York. N.Y. State Water Resour. Comm. Report of Investigation. RI-11, 21 p.

Fischer, H. B.
1968. Methods for predicting dispersion coefficients in natural streams, with applications to the lower reaches of the Green and Duwamish Rivers, Washington. U.S. Geol. Surv. Prof. Pap. 582A, 27 p.

Leopold, L. B.
1953. Downstream change of velocity in rivers. Am. J. Sci. 251:606-624.

Morisawa, M.
1968. Streams: their dynamics and morphology, p. 175 McGraw-Hill, N. Y.

APPENDIX

SAMPLE COMPUTATIONS

LOLO CREEK - PARALLEL

1.	$Q = 35.9$ ft^3/s; $\bar{v} = 1.21$ ft/s; pH = 8.0				
2.	Distance, ft	30,000	25,000	20,000	15,000
3.	A. T_L, h	6.88	5.75	4.60	3.44
	B. T_E, h	2.06	1.75	1.44	1.10
4.	A. C_u, p/m ft^3/lb s	3.50	4.00	4.75	5.80
	B. pounds NH_3	111.0	111.0	111.0	111.0
	C. C_p, p/m	10.8	12.4	14.7	17.9
	D. C_E, p/m	9.0	10.3	12.2	14.9
	E. C_{Eu}, p/m	.47	.54	.64	.78
	F. T_T, h	18.0*	3.7	1.35	.84
5.	T_E/T_T	.11	.47	1.07	1.31

BLODGETT CREEK - PARALLEL

1.	$Q = 11.7$ ft^3/s; $\bar{v} = 0.43$ ft/s; pH = 8.0				
2.	Distance, ft	12,500	10,000	7,500	8,000
3.	A. T_L, h	8.1	6.5	4.8	5.2
	B. T_E, h	2.40	1.97	1.53	1.60
4.	A. C_u, p/m ft^3/lb s	1.55	1.85	2.20	2.10
	B. pounds NH_3	76.0	76.0	76.0	76.0
	C. C_p, p/m	10.1	12.0	14.3	13.6
	D. C_E, p/m	8.36	9.96	11.9	11.3
	E. C_{Eu}, p/m	.44	.52	.63	.60
	F. T_T, h	>100.0*	4.6	1.3	1.6
5.	T_E/T_T	<.024	.43	1.2	1.0

*T_T values are drawn from figure 4, based on 50 percent mortality conditions.

VAN METER, WAYNE P., and CHARLES E. HARDY
1975. Predicting effects on fish of fire retardants in streams. USDA For. Serv. Res. Pap. INT-166, 16p., illus. (Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.)

Reports a first attempt to provide a computation system that will permit a rapid estimate of the amount of hazard to game fish caused by release of fire retardant chemical into streams. Field measurements necessary for application of the system are (1) the amount of retardant (pounds, nitrogen, calculated as NH_3) that enters a stream and (2) the discharge rate and average velocity of the stream, both measured at or near the point of retardant introduction. The result is an estimate of the time, or distance, necessary to allow dilution of the pollutant by shear and turbulent mixing to produce nonlethal conditions.

OXFORD: 432.3, 843.1.
KEYWORDS: aerial fire suppression, fire retardant chemicals, hydrology, fish toxicology, fire management, dye studies.

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GROWING
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Seedbed Characteristics In Western Larch Forests After Prescribed Burning

Raymond C. Shearer

USDA Forest Service
Research Paper INT-167
1975

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT

The Northern Region and the Intermountain Forest and Range Experiment Station are jointly supporting a series of studies of prescribed fire and their applications to forest management. Groups of scientists are investigating the effects of a wide range of fire intensities on forest regeneration, watershed values, wildlife habitat, and atmospheric resources. This publication is one of a series reporting the results of these efforts.

THE AUTHOR

RAYMOND C. SHEARER received a B.S. degree in Timber Management in 1957 and an M.S. degree in Silviculture in 1959, both from Utah State University. Currently he is completing requirements for the Ph.D. in Forest Ecology at the University of Montana. Since 1957 he has been a Research Silviculturist, assigned to the Station's Silviculture of Northern Rocky Mountain Larch, Lodgepole Pine, and Spruce Ecosystems research work unit at the Forestry Sciences Laboratory in Missoula, Montana. His primary assignment has been the study of natural and artificial regeneration of western larch and associated species.

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SEEDBED CHARACTERISTICS IN WESTERN LARCH FORESTS AFTER PRESCRIBED BURNING

Raymond C. Shearer

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401
Roger R. Bay, Director

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ABSTRACT

Establishment of western larch (Larix occidentalis Nutt.) seedlings is favored by site preparation that reduces both the duff layer and the sprouting potential of competing vegetation. A cooperative study of the use of fire in silviculture in northwestern Montana provided conditions to research the effectiveness of prescribed burning of logging slash from May through October for seedbed preparation. Greatest duff reduction, nonconiferous root mortality, and soil heating occurred when water content of duff and of soil was lowest. Slash must be burned in the summer when the duff is dry to significantly reduce the organic mantle.

However, duff on north-facing slopes dries more slowly than on other aspects, and frequent summer rainfall may prevent effective preparation of seedbeds on north slopes. Burning to prepare seedbeds for establishment of regeneration can be conducted over a wider range of time on east-, south- and west-facing slopes.

INTRODUCTION

Removal of trees from western larch (*Larix occidentalis* Nutt.) forests changes the nergy and moisture budgets at the ground surface (fig. 1). The volume of timber emoved, the means of its removal, and the aspect of the site influence the amount of irect and indirect sunlight reaching the forest floor and thus, the amount of heating f slash, duff, and upper soil. Radiation and reflection from the slash, duff, and pper soil and convection also increase. Transpiration and interception of precipitation ecrease when a timber stand is cut, particularly clearcut; so more water is temporarily vailable in the soil. Evaporation of soil water remains low as long as vegetation and ead organic residue protect the forest floor from direct radiation and surface wind. ecause of the change in energy and water budgets, the composition of the lesser vegeta- ion may change.

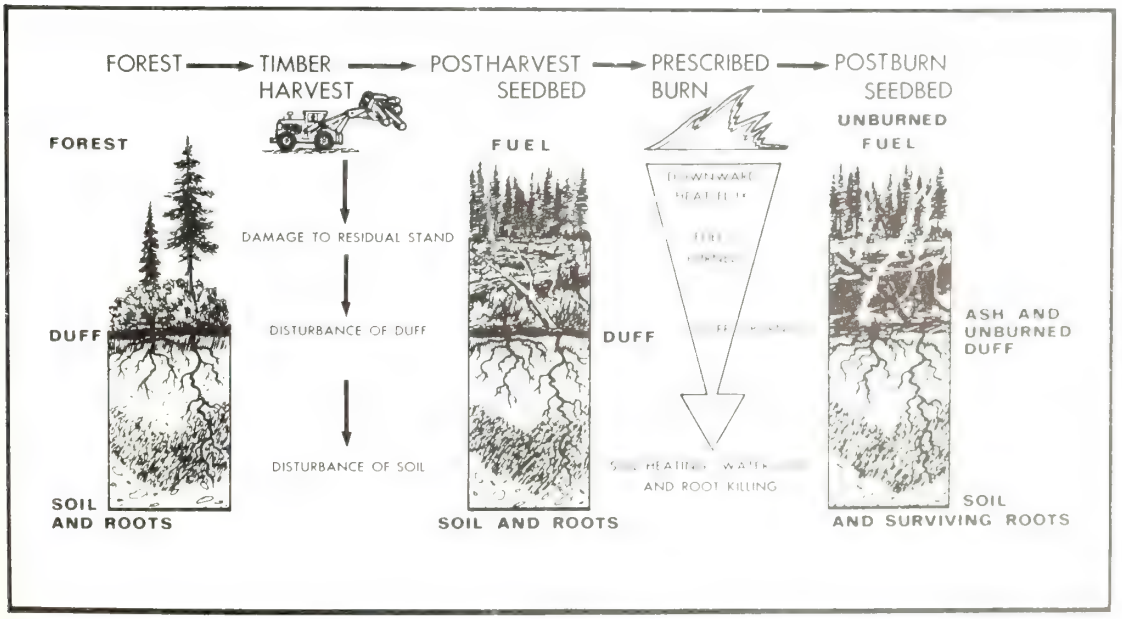

Figure 1.--Generalized sequence of changes in forest stands caused by harvest cutting and prescribed burning.

Successful establishment of western larch, a shade-intolerant tree, usually requires further alteration of the site after timber harvest through exposure of the mineral seedbed by scarification or burning and suppression of vegetative competition until seedlings attain a dominant position in the stand. Site preparation by prescribed burning should expose well-distributed patches of soil where the sprouting potential of competing vegetation is substantially reduced. If too much area is exposed, the probability of overstocking from natural regeneration increases and may require costly precommercial thinning to form a stand of desirable density at a later date.

A good initial indicator of the effectiveness of a prescribed burn to decrease competition is reduction in the number of living roots of nonconiferous species within the surface soil. The amount of root mortality is affected by several interrelated variables (fig. 1). Fire intensity is a function of the fuel load and its water conten as well as the atmospheric temperature and moisture variables at the time of burning. Downward heat flux through the duff and into the soil is dependent on the water content and the depth of duff and on the water content of the soil.

A cooperative project was begun in 1967 to study the effects of prescribed burning on (1) site preparation for conifer regeneration, (2) air and water quality, (3) erosio and runoff, (4) the nutrient status of the soil, and (5) wildlife habitat. These burn sites varied greatly by aspect, and the amount and nature (especially water content) of fuels. This variety provided a range of conditions that formed a basis for evaluating site preparation for regeneration.

This paper describes the effectiveness of several prescribed burns to reduce the amount of duff and to kill roots growing within the surface 4 inches of soil (fig. 2). In addition, soil water before and after burning and soil temperature during burning were studied to help evaluate root mortality.

Figure 2.--Portion of a 10-acre clearcut: A. The day of the prescribed burn (July 25, 1967); B. 14 days after burn (September 6, 1967); C. 14 months after burn (September 26, 1968); and D. 4 years after burn (June 7, 1971).

B
C
D

LITERATURE

Plant tissue is damaged or killed when exposed for several minutes to temperatures ranging from about 125° to 130°F (Hare 1961). Although aerial portions of plants usually are burned by fire, the roots generally are well protected from the killing effects of heat by the soil (Beadle 1940). Even dry soil has low thermal conductivity, and additional soil water further increases the energy required to raise the temperatur of the soil (Baver 1959). Thus, a greater amount of energy is necessary to heat a soil to a lethal temperature at high soil water contents than at low soil water contents. In addition, Van Wagner (1970) found that temperature increased little in mineral soil when 0.5 inch or more of duff remained unburned after a prescribed fire. The amount of bared soil was strongly related to the weight of consumed duff and, to a lesser extent, to the water content of duff (Van Wagner 1972). He also attributed nonuniformity in depth and water content of the duff layer to the amount of bared soil.

As the surface soil temperature increases from energy released during burning, hea flows along a gradient from the surface to the cooler layers below (Baver 1959). As soil temperature increases, root tissue near the surface begins to die. The intensity of the fire, coupled with the moisture content of the soil, greatly determines the success of broadcast burn in providing a seedbed.

STUDY AREA AND TREATMENT

The study area is in the adjacent Miller Creek and Martin Creek drainages on the Flathead National Forest in northwestern Montana (lat. 48°31'N., long. 114°43'W). Sixty 10-acre units, 15 on each of the four cardinal exposures, were clearcut in 1966 and 1967. Data reported in this paper were gathered from about half of these units in 1967 and 1968. The timber stands averaged 24 M bd. ft. per acre. The overmature stand was comprised mainly of western larch, Engelmann spruce (*Picea engelmannii* Parry), and Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) in nearly equal volumes. Most of the area is classified as an *Abies lasiocarpa/Pachistima myrsinites* habitat type by Daubenmire and Daubenmire (1968). While studying Miller Creek habitat types in 1971, Robert D. Pfister, Intermountain Station, recognized two phases of this habitat type: *Menziesia* phase, primarily on steep north slopes, to *Xerophyllum* phase, primarily on south-facing slopes, but also on steep west-facing slopes. (See table 1 for habitat type and burn date for each unit.)

Topography is moderately steep, with slopes ranging from 10 to 50 percent (20 percent average). Elevations range from 4,200 to 5,000 feet. The soil, derived from glacial till (10 to 25 feet in thickness) of argillite and quartzite, is gravelly loam from the Wallace (Belt) formation (R. C. McConnell unpublished data).

le 1.--*Habitat type, date burned, and average water loss [illegible] unit of the Miller Creek study, Flathead National Forest.*

Unit	Habitat type[1]	Date burned	Can water loss	Unit	Habitat type[1]	Date burned	Can water loss
NORTH				SOUTH			
1	AP	Control[2]	--	1	X	5/18/68	
2	AP	Control	--	2	X	5/18/68	
3	AP	Control	--	3	X	5/18/68	
4	M	8/31/68	497	4	X	7/3/68	407
5	M	10/9/67	495	5	X	9/30/68	135
6	M	9/10/68	303	6	X	8/23/67	
7	M	6/18/68	241	7	X	8/23/67	1,382
8	M	9/10/68	266	8	X	8/8/67	784
9	M	7/26/68	688	9	X	10/5/67	455
10	M	Control	--	10	X	7/3/68	615
11	M	8/3/67	1,119	11	X	Control	
12	M	8/3/67	1,062	12	X	8/23/67	
13	M	7/8/68	609	13	X	8/23/67	
14	M	10/3/68	126	14	X	8/23/67	
15	M	10/3/68	137	15	X	8/23/67	
EAST				WEST			
1	AP	10/10/67	827	1	AP	7/25/67	799
2	M	Control	--	2	X	8/23/67	1,473
3	M	8/7/68	940	3	X	9/30/68	423
4	M	7/18/68	480	4	X	9/5/68	53
5	M	7/5/68	525	5	X	8/23/67	1,610
6	AP	10/2/67	243	6	X	8/23/67	
7	AP	7/18/67	728	7	X	8/23/67	1,926
8	AP	10/1/70	--	8	X	7/24/68	513
9	AP	10/1/70	--	9	AP	10/7/67	737
10	AP	9/9/68	415	10	X	7/16/68	519
11	AP	8/23/67		11	AP	6/6/68	47
12	AP	8/23/67		12	AP	8/30/68	556
13	AP	8/23/67	1,251	13	AP	8/30/68	266
14	AP	9/9/68	379	14	AP	10/2/68	264
15	AP	7/18/67	286	15	AP	10/2/68	228

[1]Classified by Robert D. Pfister: AP = *Abies lasiocarpa/Pachistima myrsinites*; =AP, *Menziesia* phase; X = AP, *Xerophyllum* phase.
[2]Control = unit not burned.

METHODS

Root Mortality

Root mortality of nonconiferous vegetation was measured at six points within the central 2.5 acres of each unit. At each sample point, a vertical face about 10 inches in length and 5 inches in depth was exposed. Then, excess soil around the roots was lightly scraped away; so roots were fully visible. If the roots had not been cut, they were then cross-sectioned.

Next, an 8- by 4-inch grid was pressed against this face and nonconiferous roots were identified either as living or dead by means of a chemical test similar to that described by Hare (1965) and Steel and Henderson (1967). A solution of 1 percent (by weight) orthotolidine [$(-C_6H_3-4NH_2-3-CH_3)_2$] in 95 percent methanol was mixed and stored in a capped spray bottle. A second spray bottle contained a solution of USP 3 percent hydrogen peroxide (H_2O_2). These solutions react with the enzyme peroxidase in living plant cells and form a dark-blue product. Because peroxidase denatures when the cell dies, no color change occurs when these chemicals are sprayed on dead cells.

The orthotolidine and hydrogen peroxide solutions were sprayed on the surface enclosed by the grid. Immediately, living roots turned blue. Those that exhibited no color change were classified as "dead." From 10 to 30 seconds were allowed for the toxic vapor from the alcoholic orthotolidine to disperse before the roots were counted. Living and dead roots over 1 mm in size were counted at six levels.

The original intent of the study was to compare the number of living roots on nonconiferous vegetation before and after burning on the blocks. Preburn samples on the first two blocks showed that over 99 percent of these roots were alive. Subsequently, only postburn root sampling was done, and all roots were considered to be alive before burning. Although some natural root mortality probably occurred through the summer, it was thought to be minimal because soil moisture was not a limiting factor on these cutover areas before burning. Separate identification of nonconiferous plant species by their roots was not attempted.

Soil Water

Soil water from samples collected the afternoon of and morning after burning was determined gravimetrically by using the following equation: Percent soil water $= \frac{\text{wet soil weight - dry soil weight}}{\text{dry soil weight}} \cdot 100$. The six sample locations for root mortality measurements were also used to sample soil water. The preburn and postburn samples were taken about 16 inches apart and from the following levels at each sample point: 0-0.5, 0.5-1, 1-2.25, 2.25-4 inches.

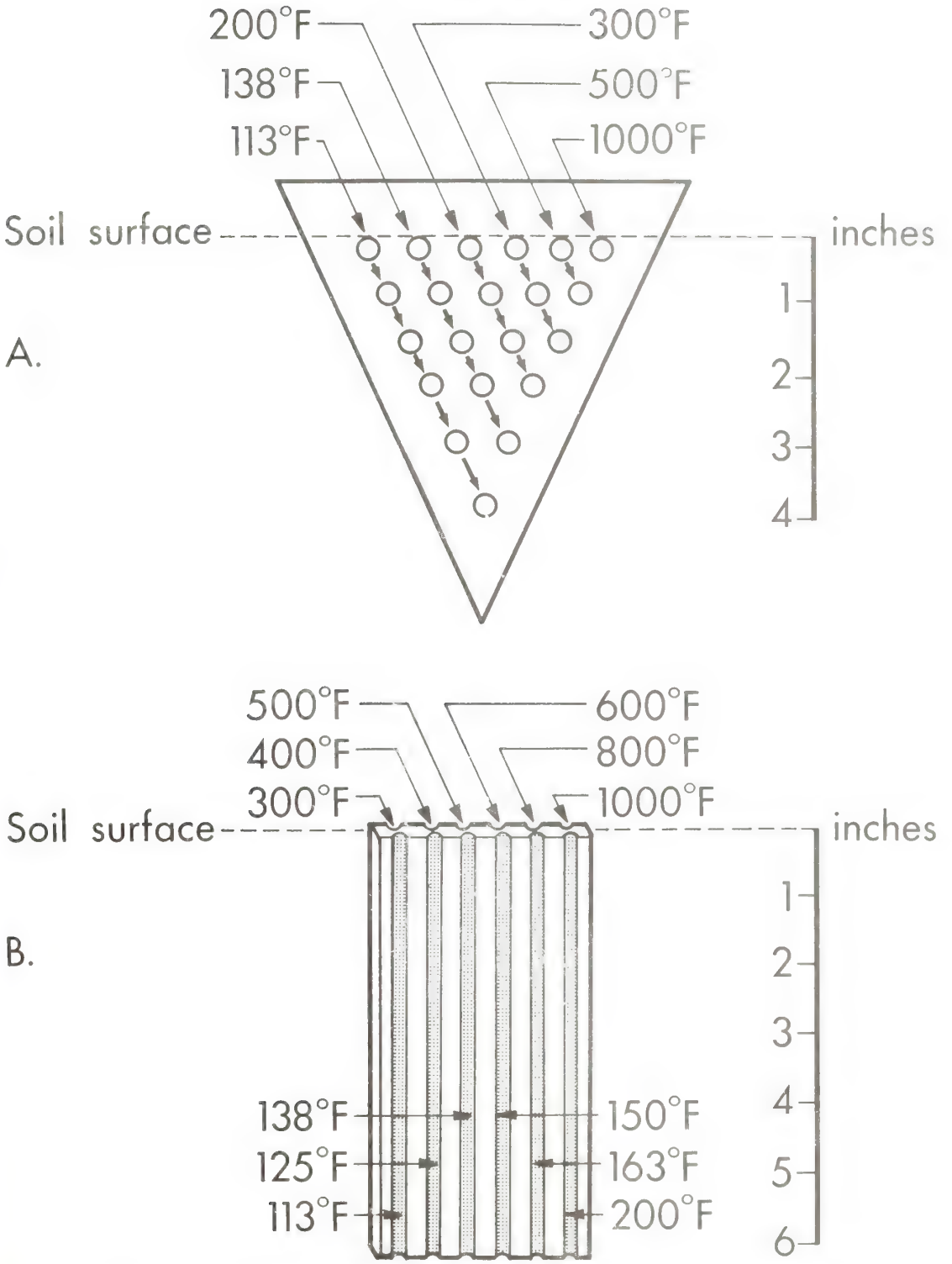

Figure 3.--Schematic showing [illegible] to indicate the temperature gradient within the soil during prescribed burning. (A) Triangular wedge used in 1967 showing placement and melting points of Tempil®. (B) Rectangular strip used in 1968 showing spacing of depressions and melting points of Tempilaq®.

Soil Temperature

The maximum temperature within the upper 4 to 6 inches of soil was estimated by using Tempil Pellets or Tempilaq (Tempil Division, Big Three Industries, Inc., South Plainfield, N. J.) with melting points ranging from 113° to 1000°F. Tempil Pellets ar temperature-sensitive tablets (7/16-inch diameter and 1/8-inch high) and Tempilaq is a temperature-sensitive material suspended in an inert, volatile, nonflammable vehicle. In 1967, triangular asbestos wedges were used to hold Tempil Pellets of six melting points (fig. 3a). From 25 to 36 wedges were placed within a central 2.5-acre study plot on each unit prior to burning so that the upper edges of the top row of Tempil Pellets were at the mineral soil-duff interface. Tempil Pellets indicated the approxi mate maximum temperature at various levels within the soil. Rectangular asbestos stri were used in 1968 that had six full-length depressions scored on both sides. Each de- pression was filled with a Tempilaq of a different melting point that dried in about 1 minute (fig. 3b). The strips were evenly spaced at 36 points within the central 2.5-acre study plot on each burn in 1968 and the upper edge of the asbestos was posi- tioned along the soil-duff surface. These strips gave a better indication of the temperature gradient within the soil during burning than the wedges used in 1967 and were easier to insert in the soil and to maintain.

Tempils and Tempilaq indicate instantaneous maximum temperature, but give no info mation on the duration of that temperature. Temperature duration was estimated on a few burns by using battery-operated recorders connected to thermocouples installed at two locations at 0.2, 0.4, 0.8, and 1.6 inches in the soil. At the 0.2-inch depth, chromal/alumel thermocouple probes were used and at all other depths, iron/constantan thermocouple probes were used.

Analysis

The relations of soil temperature, soil water loss, and nonconiferous root mortal to preburn soil water content and water loss from water can analogs were all explored and expressed mathematically (appendix) by using techniques specified by Jensen and Homeyer (1970, 1971) and Jensen (1973). The same techniques were used to develop the relation between duff reduction and duff moisture content. It is anticipated that som or all of these mathematical models will be pertinent input to larger information systems currently being assembled for the use of land managers.

RESULTS

Root Mortality

Reduction of roots of competing nonconiferous species by heat from prescribed fires was generally low at depths greater than 2 inches (table 2) except in dry soil.

Time of Burning

Root mortality caused by soil heating during burning increased within the surface 2 inches of soil as the hot, dry summer of 1967 progressed; mortality decreased rapidly after rainfall started in October (fig. 4). In contrast, root mortality was lower throughout the cool, wet summer of 1968 than at any time in 1967.

Table 2.--*Root mortality by depth for units where data was taken, Miller Creek Study, Flathead National Forest.*

Unit	Root mortality by depth (inches)					
	0-1/2	1/2-1-1/4	1-1/4-1-3/4	1-3/4-2-1/4	2-1/4-3	3-4
	Percent					
NORTH						
5	55	24	15	13	16	15
7	54	56	38	21	6	0
8	0	0	0	0	0	0
9	13	22	11	14	0	0
11	100	86	63	20	5	4
13	12	0	0	0	0	0
EAST						
3	40	19	0	0	0	0
5	7	12	0	0	0	0
6	86	85	69	30	0	0
7	36	22	6	12	4	0
10	36	0	25	0	0	0
13	100	83	88	78	89	50
SOUTH						
4	20	23	12	0	0	0
8	100	67	46	18	6	4
10	11	30	6	6	9	0
WEST						
1	68	30	15	6	0	0
4	7	0	0	0	0	0
8	27	17	0	0	0	0
9	86	74	42	15	19	5
10	36	17	0	0	0	0
12	14	12	0	14	0	0

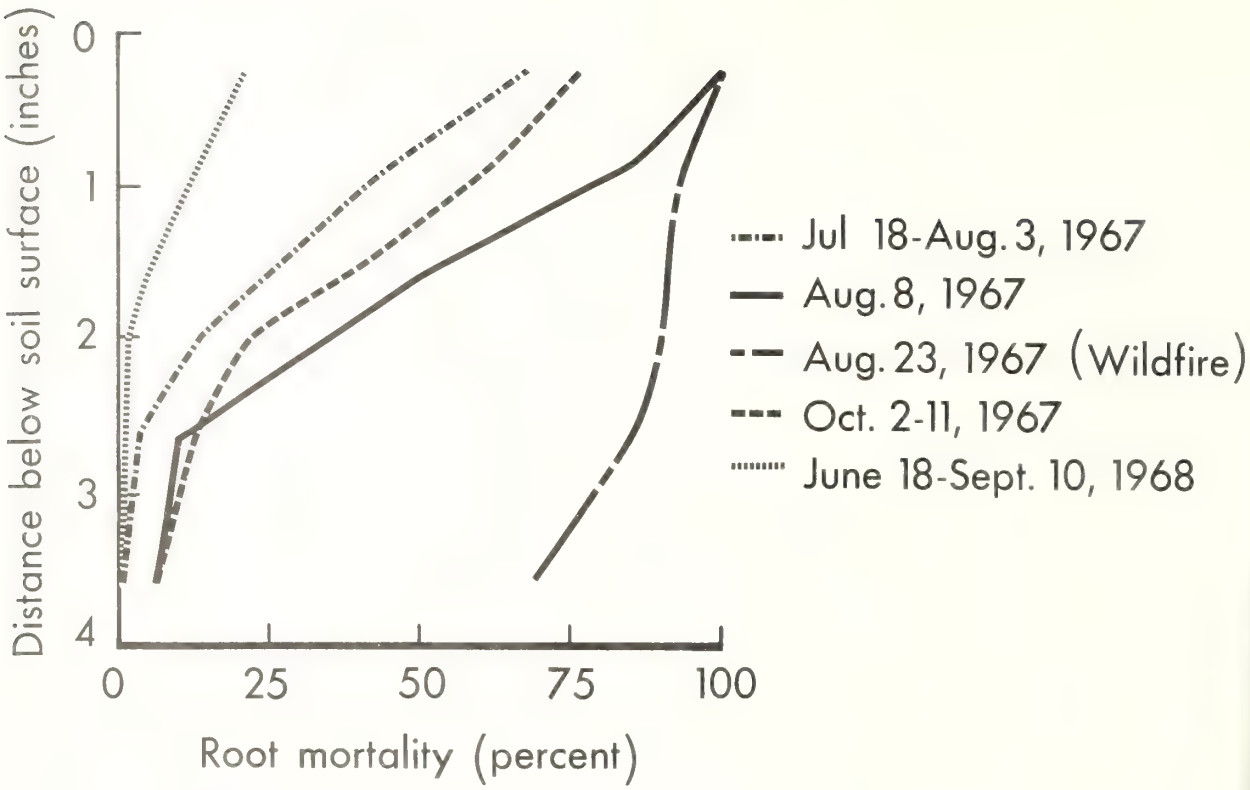

Figure 4.--Root mortality within the surface 4 inches of soil by date of burn following burning of slash on cutover blocks.

Except for areas burned by the wildfire on August 23, most root mortality in 1967 was confined to the surface 2 inches of soil and to the surface 1 inch in 1968 (fig. 4). Heat from the August 23 wildfire, which burned when soil conditions were extremely hot and dry, caused the only significant reduction of roots as deep as 4 inches below the soil surface. Over 90 percent of the roots died within the upper 2.4 inches and 70 percent of the roots died within the 3.3- to 4.0-inch layer (fig. 4). In addition, the wildfire reburned a unit initially burned 1 month earlier and consumed nearly all remaining duff and some partially burned fuels. Root survival dropped from 80 to 11 percent within the surface 2.5 inches and from 98 to 38 percent within the 2.5- to 4-inch level.

After rainfall began in October 1967, root losses decreased on each successively burned unit. Root mortality was much more variable in the fall than in July and early August. Samples taken from points that burned to the soil surface generally showed high root mortality; soil water greatly influenced the depth of root kill.

Considerable sprouting began immediately after burning in June, July, and August when root kill was generally low (fig. 5). Alder (*Alnus sinuata* (Regel) Rydb.) frequently sprouted vigorously (fig. 5a), as did mountain maple (*Acer glabrum* Torr.) and Scouler willow (*Salix scouleriana* Barratt). Beargrass (*Xerophyllum tenax* (Pursh) Nutt.) leaves continued to elongate without any apparent interruption despite the fire (fig. 5b).

*Figure 1.--A. Sprouting of shoot (*Abies sinuata *Regel) after a prescribed fire that burned the old crown. B. Leaf elongation of beargrass* (Xerophyllum tenax *(Pursh) Nutt.) after a prescribed fire.*

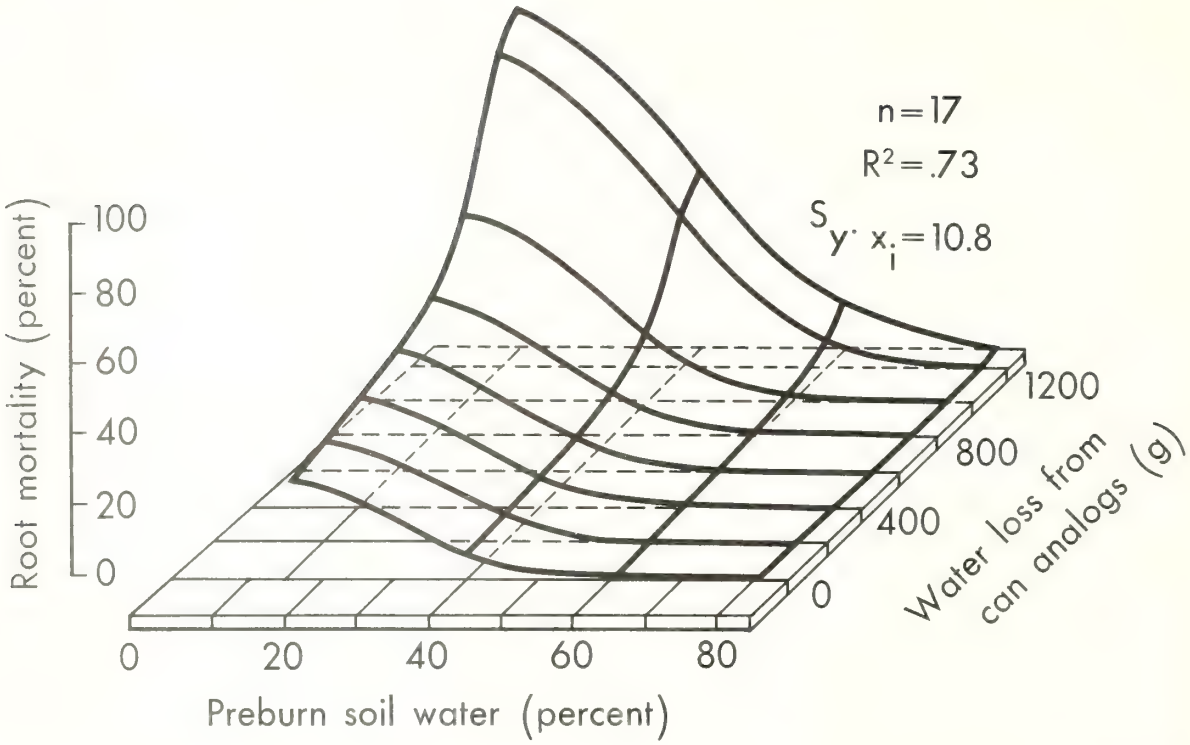

Figure 6.--Average root mortality within the upper 4 inches of soil during prescribed burning as related to the preburn soil water within the surface inch and average water loss from can analogs (a measure of fire intensity).

Influence of Fire Intensity and Soil Water

Root mortality varied from 0 to 100 percent (fig. 6) according to the interaction of the amount of water in the soil and the energy released from prescribed fires (represented by water loss from cans placed in direct contact with the surface of the soil (Beaufait 1966)). In the spring or sometimes late fall, when soil water was near or at field capacity (about 50 percent on the more sheltered sites), root mortality ranged from 0 to 30 percent, regardless of fire intensity. From midsummer to late summer of drier years when soil water declined to about 15 percent on the more exposed sites, root mortality ranged from 30 to nearly 100 percent.

Mortality varies greatly according to the depth at which roots grow in the soil. When soil water is high, most root mortality occurs within the surface half inch, regardless of fire intensity. However, when soil water is low, high-intensity burns kill most roots within the surface 4 inches of soil. Burns of lower intensity on dry soils cause high root mortality in the surface 1 or 2 inches, but have little effect on roots at lower depths.

Soil Water

Within the surface 4 inches of soil, water varied (table 3) with the amount and pattern of summer precipitation, with soil texture, and with such management practices as harvest cutting and seedbed preparation.

Table 3.--*Soil water before (B), and after (A), [illegible] data were taken, Miller Creek Study, Flathead National Forest*

Unit	Soil water by depth (inches)							
	0 to 1/2		1/2 to 1		1 to 2-1/4		2-1/4 to 4	
	B	A	B	A	B	A	B	A
	Percent							
NORTH								
7	45	50	47	39	44	38	47	40
8	49	49	41	44	41	46	40	47
9	30	37	37	32	36	34	33	[illegible]
11	41	31	40	34	43	36	36	38
13	43	42	42	36	39	38	39	[illegible]
EAST								
3	33	[illegible]	32	32	31	32	31	[illegible]
5	48	45	52	42	49	41	52	42
6	22	12	17	17	18	17	18	17
7	32	25	28	25	28	26	30	27
10	44	39	38	35	40	38	[illegible]	41
13	25	11	29	21	28	25	27	26
SOUTH								
7	--	2	--	5	--	8		[illegible]
8	11	10	13	13	12	[illegible]	12	14
9	28	19	23	19	22	20	18	[illegible]
10	43	42	47	40	44	42	44	41
WEST								
1	43	43	42	40	41	42	[illegible]	40
2	-	11	--	12	--	12	--	12
4	37	29	33	28	34	29	35	27
5	--	9	--	10	--	12		
6	--	2	--	2	--	3	--	1
7	--	8	--	10	--	12	--	
8	31	30	27	26	26	[illegible]		
9	36	26	30	31	30	[illegible]		[illegible]
10	32	37	33	27	30	[illegible]		
12	42	36	30	33	31	33		
13	36	38	30	32	28	28		
14	46	--	42	--	41		44	

ummer Precipitation

Frequent precipitation was needed to maintain soil water during the summer months hen vegetation required large amounts of water to support growth. In 1967, the water n the upper 4 inches of soil decreased rapidly in the uncut stands from June through eptember and in cutover, but unburned, units from late July through September. In 1968, owever, soil water failed to decline as it had the previous year because of frequent

rain showers. Less than half as much rain fell on the Keith Mountain study area 20 miles south of Fortine, Montana, from June through September 1967, as was recorded during the same period in 1968:

Month	*Precipitation (inches)* 1967	1968
June	3.91	3.05
July	.14	.36
August	.00	1.99
September	.30	3.74
Total	4.35	9.14

This amount was only about 30 percent of average in 1967, but nearly 160 percent of normal in 1968 (U.S. Environmental Science Services Admin. 1967, 1968).

Soils

Paul E. Packer, Intermountain Station, found that the water-holding capacity of th soils at Miller Creek varied with the proportion of soil particles greater than 2 mm in size. These soil features are also closely related to habitat type and to aspect:

Water-holding capacity (tension, cm) 20	60	*Proportion of soil particles >2 mm in size*	*Aspect*	*Habitat type*
- - - - *Percent* - - - -				
48	42	28	N, E	*Abies/Pachistima (Menziesia* phase)
44	39	40	N, E, W	*Abies/Pachistima*
38	32	53	W, S	*Abies/Pachistima (Xerophyllum* phase)

In May, soon after snowmelt, when the upper 4 inches of soil was at or near saturation, soil water was greatest on units with the *Abies/Pachistima* habitat type (*Menziesia* phase) and was least on units with the *Abies/Pachistima* habitat type (*Xerophyllum* phase). Later, soil water depletion was more severe on the *Abies/Pachistima* habitat type (*Xerophyllum* phase) than on either of the other cover conditions. When fall rains began in 1967, soil water on unburned units had declined to about 15 or 20 percent on the *Abies/Pachistima* habitat type (19 percent on unit East 6). Soil water was estimated to be about 25 to 30 percent on unburned units with *Menziesia* and about 5 to 15 percent on units with *Xerophyllum*. In contrast to 1967 totals, soil water on most unburned units remained high during the wet summer of 1968.

The amount of water within the surface 4 inches of soil also varied by the topographic position of the unit on the slope. As indicated in the previous tabulation, there was an overlapping of soil characteristics by aspect. Some upper north- and east facing sites had greater water-holding capacity and fewer coarse fragments than those lower on the same slopes, as evident by a change in habitat type. Some lower, less steep, west-facing slopes held more water than upper or steeper west aspects and showed distinct habitat type differences also.

Effect of Cutting

Depletion of water in the upper 4 inches of soil by vegetation is considerably reduced on clearcut and slashed areas when compared with adjacent uncut stands (table 4). This results because transpiration is drastically decreased when the timber and other

Table 4.--[illegible] and slashed unit adjacent to each, August 2, 1968

Soil depth (inches)	Soil Water					
	Unit North 9			Unit East 3		
	Uncut	Cut	Difference	Uncut	Cut	Difference
	-Percent-					
0-1/2	18	40	22	25	[illegible]	[illegible]
1/2-1	18	37	19	22	[illegible]	[illegible]
0-4	[illegible]	35	17	21	[illegible]	11
Average	[illegible]	35	17	21	[illegible]	10

egetation are removed by logging and slashing operations. In addition, evaporation rom the surface does not increase greatly as long as logging slash shades the ground nd physically suppresses the low vegetation. Large differences were evident in early ugust (table 4) but before remeasurements were made on these units later in 1968, eavy summer rainfall recharged the upper soil on both cut and uncut plots and eliminated he differences. Similar measurements were not taken in 1967, but soil water differences etween cut and uncut stands probably would have shown greater divergence later in the ummer.

[illegible]

Prescribed burning in June and July reduced soil water only slightly because all ut the fine fuels were wet and the soils were near field capacity (table 3). By late uly, only soils sampled on north-facing slopes (*Menziesia* phase of the *Abies/Pachistima* abitat type) remained near field capacity; those on the south-facing slopes (*Xerophyllum* hase of the *Abies/Pachistima* habitat type) were much drier. In addition to being roughtier, the soils on southerly exposures had a higher evaporation rate because of reater insolation.

The effect of topographic position was evident on units East 7 and West 1. Both upport the *Abies/Pachistima* habitat type and were burned a week apart in 1967. A imilar amount of energy was released during each fire. However, the effects of burning ere different (table 5) because unit East 7 is on an upper, exposed, and steep, east- acing slope that has slightly coarser soil of lower water-holding capacity than unit est 1, which is on a lower, moist, and gentle west-facing slope. Snowmelt occurred bout 2 weeks earlier on unit East 7 than on unit West 1. Because less water was held n the lower duff and soil of East 7, nearly 2.5 times more duff was burned (table 6) nd considerably more water was removed from the surface 1 inch of soil (table 3) on nit East 7 than on unit West 1.

In 1967, the soil continued to dry through August and September. A wildfire burned nit East 13 on August 23 and the soil moisture decreased 14 and 8 percentage points ithin the 0 to 0.5 and 0.5 to 1-inch levels (table 3). This reduction was greater than hat following any other prescribed fire measured at Miller Creek.

After the fall rains began in 1967, burning reduced soil water mainly in the upper ne-half inch. At first, the rain had relatively little effect on the upper soil be- ause it was intercepted by the fuels and then either evaporated or was absorbed by the lash and duff. These wet fuels burned poorly except where they were concentrated. s water increased within the duff and soil following additional rainfall, burning ecame less effective in reducing overall surface moisture.

Table 5.--*Effect of soil water on the depth of heat conduction during prescribed burns of similar intensity*[1]

Units	Water		Depth of soil heating	
	Soil (Surface inch)	Duff (Lower half inch)	138°F	200°F
	Percent by weight		*Inches*	
South 10 and North 13	44	195	0.2	0.0
North 9	38	96	.4	.0
West 9 and East 7	31	53	.8	.2
South 8	12	28	1.6+	.5

[1]Water loss from can analogs averaged between 609 and 784 g.

Table 6.--*Maximum, minimum, and average duff depth before burning, average depth of unburned duff after burning, and average reduction for units where data were collected, Miller Creek study, Flathead National Forest*

Unit	Duff Depth				
	Before burning			After burning	
	Maximum	Minimum	Average	Average	Reduction
	Inches				*Percent*[1]
NORTH					
4	5.1	1.6	3.0	1.6	46
7	4.0	1.4	2.6	1.7	35
8	8.5	1.1	--	--	--
9	5.9	0.7	2.4	1.2	51
11	4.5	1.1	2.6	0.9	66
13	4.7	0.8	2.8	1.9	35
EAST					
3	4.9	0.6	2.7	1.0	63
5	4.5	0.8	3.1	2.1	32
6	4.1	1.4	2.4	1.0	56
7	4.8	1.0	2.7	0.6	78
10	6.7	0.1	2.7	1.6	42
13	4.1	1.9	3.2	0.0	100
SOUTH					
4	7.1	1.0	3.4	2.1	38
8	4.1	1.4	2.7	0.4	84
9	2.3	0.8	1.4	0.1	93
10	3.8	0.0	2.0	1.5	25
WEST					
1	3.0	1.6	2.3	1.5	33
4	4.1	0.2	--	--	--
8	4.4	0.0	1.8	1.1	40
9	3.7	1.7	2.2	0.3	86
10	4.7	0.4	2.6	1.4	46
12	4.3	0.2	2.5	1.5	43
13	3.9	1.0	2.7	1.8	34

[1]Determined from unrounded data.

In 1968, frequent rainfall occurred after August 10 and the surface 4 inches of soil was quickly recharged. Soil water was little reduced by burning (table 3) at any time in 1968.

The wildfire of August 23, 1967, burned when fuels were dry and moisture in the upper 1 inch was low. The lowest postburn soil water recorded in this study occurred on four cutover units located on west- and south-facing slopes and on one uncut unit located on a west-facing slope. The wildfire burned nearly all the duff and probably reduced soil water substantially. As shown in the following tabulation, postburn soil water in the 1- to 4-inch level averaged 11 percent on the cutover units South 7, West 2, West 5, and West 7, and 4 percent on the uncut unit, West 6:

	Soil depth (inches)		
	0-1/2	*1/2-1*	*1-4*
	- - -

prescribed burning at Miller Creek. When the soil was nearly saturated (about 50 percent by weight) soon after snowmelt, the water regime in the surface 1 inch of soil decreased only 6 percent during the most intense fire (fig. 7). However, later in the summer after evapotranspiration had depleted much of this water, fire in dry fuel released enough energy to burn off nearly all the duff and dry the surface 1 inch of soil. For example, at 15 percent soil water, intense fires decreased soil water by 12 percent. Once the slash and upper duff were moistened by rain, usually in late summer or early fall, the energy released by prescribed fires diminished. Although the heat flux decreased, water loss was considerable within the upper 1 inch of soil where the surface soil and lower duff remained relatively dry, as in early October 1967. Later, soil water depletion occurred primarily under fuel concentrations or other conditions that protected the soil from the rain.

Effect of Duff

Forest litter ameliorates the effect on the soil surface of desiccation by wind an heating by incoming radiation. At Miller Creek, this layer averaged about 2.5 inches i depth (see table 6 for the average, the maximum, and the minimum depth of litter measured on each unit). In May, June, and most of July, this layer of decomposing organic matter was moist and insulated the surface soil from the drying effects of prescribed fires. On units where litter averaged more than 2 inches in depth and where the water content of the lower half of the duff was above 110 percent, less than 40 percent of the duff depth was burned during prescribed fires (fig. 8). As the water content of the litter decreased, prescribed fires consumed more of this layer and caused greater water depletion of the upper soil. When the lower half of the duff laye reached about 50 percent water content, prescribed fires burned off most of the duff layer. Concurrently, surface soil water was reduced to the lowest point.

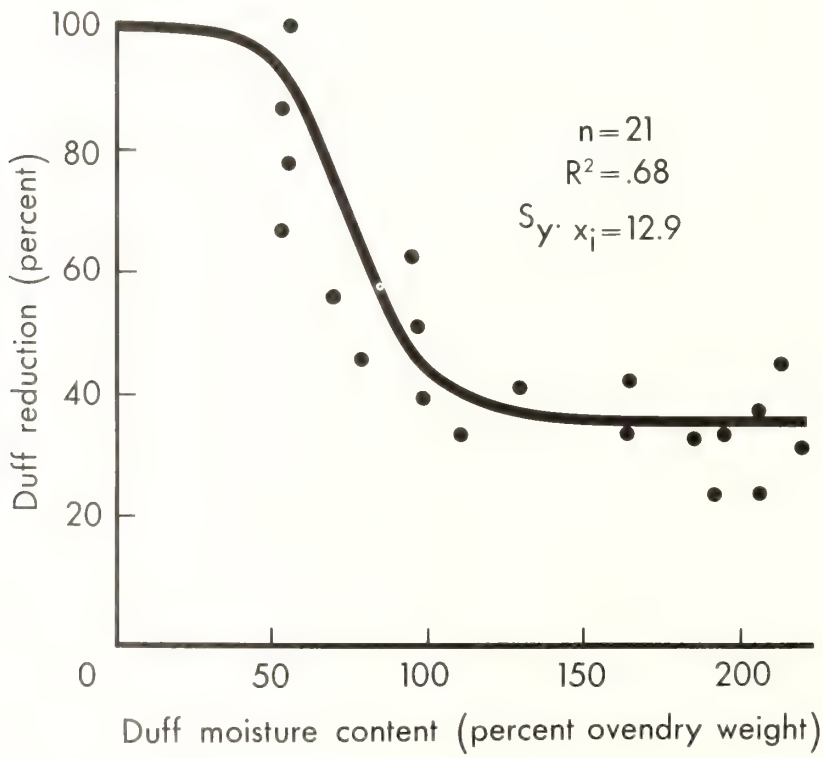

Figure 8.--Duff reduction related to the water content of the lower half of the duff layer.

Soil Temperature

The downward heat flux from the combustion of forest fuels penetrates the soil surface and heats the upper soil mantle. The increase in soil temperature varies considerably during the burning of slash.

Observations

Usually as logging slash and duff dried and soil water decreased during the summer, each successive prescribed fire became more intense and a steep temperature gradient developed within the surface soil (fig. 9). In 1967, this condition continued into the fall; extreme fire conditions forced a halt to burning from the end of August to early October. However, in 1968 frequent heavy rains, from mid-August on, replenished soil water and stopped further soil drying. Except at scattered points where fuels were concentrated, the effectiveness of fires in reducing duff layers and heating the surface

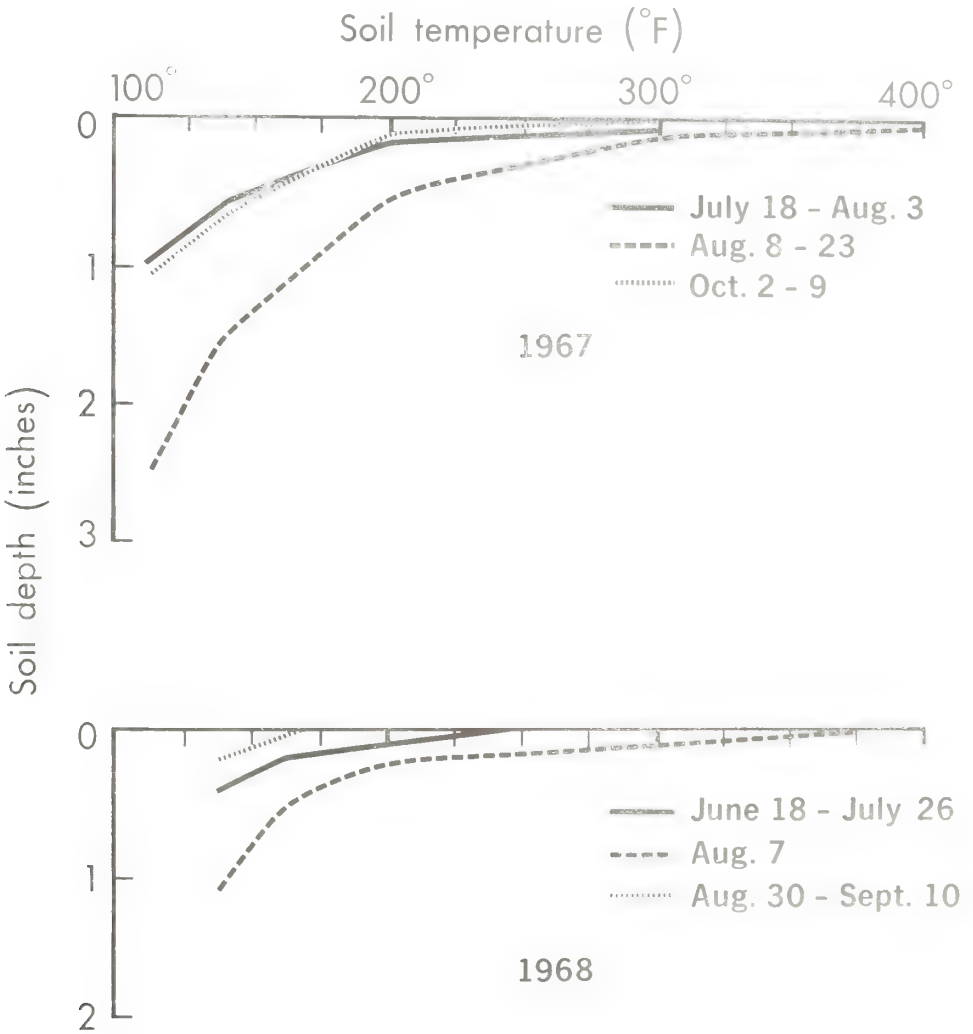

Figure 9.--Average depth temperatures were recorded during prescribed burns in 1967 and 1968.

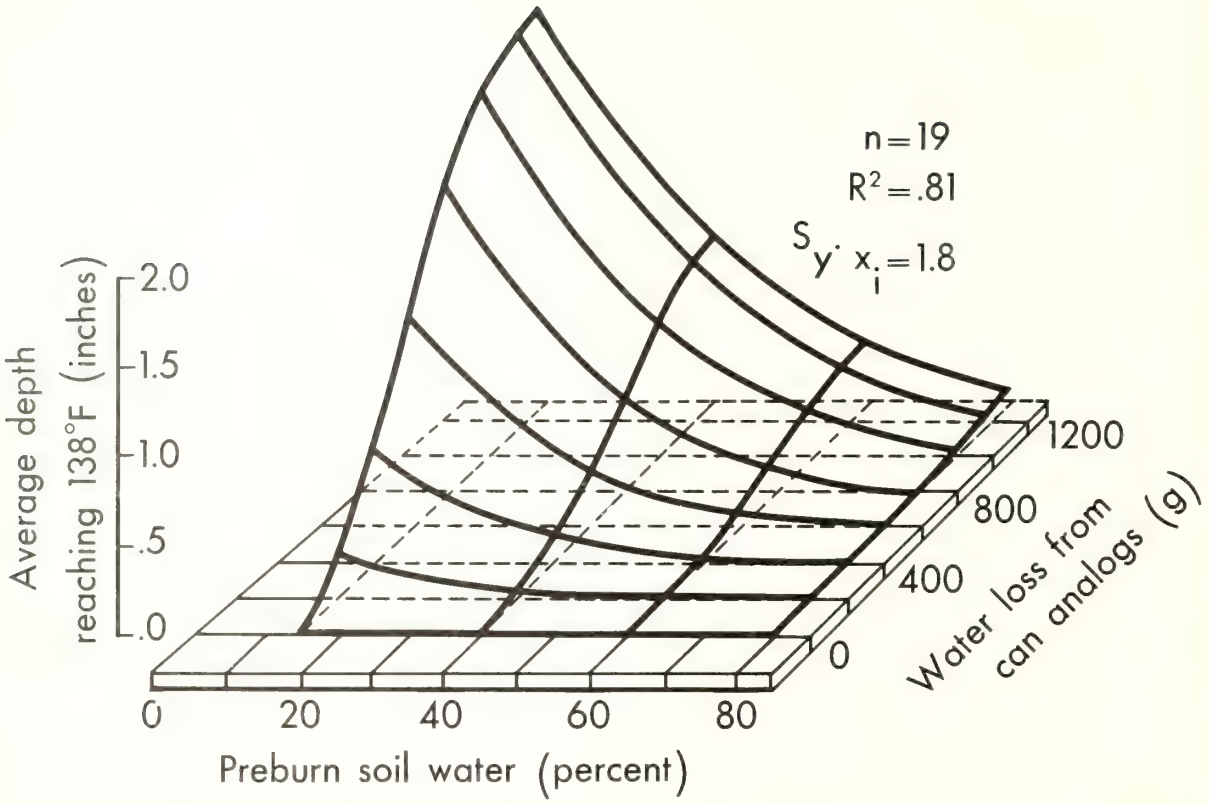

Figure 10.--Average depth that reached 138°F during prescribed burning as related to preburn soil water within the surface 1 inch and average water loss from can analogs (a measure of fire intensity).

soil diminished rapidly after heavy rainfall began. Fires in June and July caused few spots to be heated above 200°F, and then only in the surface one-fourth inch (fig. 9); temperatures over 113°F were rare below 1.5 inches. Prescribed burning in early August caused the greatest soil heating. After the heavy rains subsided and fuel dried enough to burn, the level of heat penetration decreased to or below that caused by fires ignited in June and July.

Temperature Variation

Heating of the surface soil varied according to the interaction of fire intensity and the amount of soil water (fig. 10). Variability was evident both within individual units and between units (table 7). Maximum soil temperatures were usually recorded at points of high fuel concentration, low soil water, or both. Living cells usually are killed at 158°F. In this study, the average depth that reached 138°F increased as preburn soil water decreased at any given fire intensity (fig. 10). However, the depth reaching this temperature increased rapidly with greater fire intensities. In the spring, when soil water was near field capacity (about 50 percent on the more sheltered slopes), the depth that reached 138°F increased from 0 to 0.6 inch over the extremes of fire intensity shown in figure 10. In middle to late summer, when soil water reached about 15 percent on the driest slopes, the soil was heated to 138°F from 0 to 2.2 inches depending on the intensity of prescribed fires.

Table 7.--*Maximum, minimum,*[1] *and average depths that Tempilaq melted for several temperatures at units where data were taken, Miller Creek study, Flathead National Forest*

Unit	Depth of Tempilaq melt																
	113°F			125°F			138°F			150°F		163°F		200°F			350°F	
	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Ave.	Max.	Ave.	Max.	Min.	Ave.	Max.	Ave.
	Inches																	
NORTH																		
4	--	--	--	1.2	0.0	0.2	0.9	0.0	0.2	0.9	0.1	0.2	0.0	--	--	-	-	--
5	4.0	0.0	0.3	--	--	--	3.0	.0	.7	--	--	--	--	0.6	--	0.1	0.3	0.0
7	--	--	-	.7	.0	.1	.4	.0	.1	.1	.0	.1	.0	--	--	--	--	
8	--	--	-	.7	.0	.2	.6	.0	.1	.6	.1	.3	.0	--	--	-	--	-
9	--	--	-	1.4	.0	.5	1.2	.0	.4	.9	.2	.6	.1	.4	--	.0	-	-
11	3.7	.0	.9	--	--	--	1.9	.0	.5	--	--	-	--	.6	-	.1	.0	.0
13	--	--		--	--	--	.3	.0	.2	.7	.2	.1	.1	--	-	-	-	-
EAST																		
3	--	--	--	2.1	.0	1.0	2.2	.0	1.1	.9	.9	1.1	.6	.9	--	.2	.5	1
5	--	--	--	1.4	.0	.3	1.3	.0	.2	1.0	.1	.7	.1	--	--	--	-	--
6	4.2+	.0	.9+	-	-	--	3.3+	.0	.6	--	-	--	--	1.1+	--	.2+	.3	.0
7	2.1	.4	1.1	--	-	--	1.4	.2	.7	--	--	--	--	1.0	--	.2	.6	.1
10	--	--	--	1.2	.0	.2	1.0	.0	.1	1.0	.1	.3	.0	.2	--	.0	.2	.0
13	4.2+	.7	2.5+	--	-	--	3.0+	.5	1.6+	--	--	--	--	1.4	--	.6	1.2	.2
SOUTH																		
4	--	--	--	2.4	.0	.4	1.6	.0	.3	1.5	.2	.5	.1	.0	-	.0	.0	.0
8	4.5+	.4	2.5+	--	--	--	3.6+	.2	1.6+	--	--	--	-	1.5	-	.5	.6	.1
9	1.6	.0	.6	--	-	--	.8	.0	.2	--	-	--	--	.1	--	.0	.0	.0
10	--	--	--	1.7	.0	.4	1.4	.0	.3	1.0	.2	.0	.1	-	-	-	-	
WEST																		
1	2.0	.0	.9	--	--	--	1.5	.0	.6	-	-	--	-	.9	--	-	.4	1
4	--	--	--	.6	.0	.0	.2	.0	.1	.0	.0	.0	.0	-	--	-	-	
8	--	--	--	1.3	.0	.4	1.2	.0	.2	1.2	.1	.7	.0	.6	-	.0	-	-
9	3.9+	.0	1.5	--	--	--	2.9	.0	.8	--	--	--	--	1.3	-	.3	.4	.0
10	-	--	--	--	--	--	1.3	.0	.6	1.3	.5	.6	.1	-	-	-	-	
12	-	--	--	1.2	.0	.2	1.0	.0	.2	1.0	.2	1.1	.4	-	-	-		
13	-	--	-	.5	.0	.0	.4	.0	.0	.5	.0	.0	.0	-	-	-	-	-

[1]Minimum values are all 0.0 for 150°F and greater.

The magnitude of heat penetration into the soil is also influenced by the amount of water in the duff. In early August 1967, on a moist north-facing slope, a prescribed fire caused the soil surface temperature to increase from about 50°F to between 138°F and 200°F with 113°F recorded to a depth of about 1 inch. Heat conduction increased at the lower one-half inch of duff and the surface 1 inch of soil dried (table 5). The maximum temperature at the surface varied from 200° to 500°F, with 113°F recorded at an average depth of about 3 inches and a maximum depth of about 5 inches.

In August 1967, maximum soil temperatures to 200°F ranged from 0 to 1.5 inches in depth, with an average depth of 0.5 inch, which was twice that on any other burn. About 8 percent of the units were burned when the soil water within the surface 1 inch was greater than 30 percent. Temperatures greater than 138°F were seldom recorded below a depth of 3 inches even during the hottest burns, and 200°F was rarely measured below the surface 0.5 inch of soil.

In 1967, little rain fell from mid-July through September to recharge the upper soil. Soil heating was greatest during this period. Even after rains began in early October, interception by slash, vegetation, and the duff layer prevented most of the initial moisture from entering the surface soil. Hence, surface soil water remained fairly low and fires, even fires of low intensity, heated the soil considerably.

During this period, water within the lower 0.5 inch of duff averaged 28 percent and water within the surface 1 inch of soil averaged 20 percent. In contrast, when water content of duff and soil was high and fires similarly low in intensity burned, little or no increase in soil temperature occurred.

Duration

To some extent, the length of time that high temperatures are maintained in the soil surface causes physical and biotic changes within that layer. As soils dry, the heat flux from fires causes greater and longer heating within the surface soil. The most extreme soil heating measured at Miller Creek is shown in figure 11, point 4. Thi figure illustrates the increase and duration of temperature in the upper 1.8 inch of so and the variability measured at two points on a south-facing slope burned in early August. Soil temperature maximums varied from 130° and 360°F at the 0.4-inch depth, to 103° and 155°F at the 1.6-inch depth. The sudden rise to 621° and 252°F at the 0.4-inc and 0.8-inch depths, respectively (fig. 11), shows the influence of the ignition of a root within the soil--temperature was not increased at 1.6 inches. While the tempera- ture at the 0.4-inch depth just reached 130°F at point 27 (fig. 11), it was greater than 130°F at point 4 for about 6, 5, and 3-1/2 hours at depths of 0.4, 0.8, and 1.6 inches, respectively. The soils had not returned to ambience by the time the instrumen were removed the next morning.

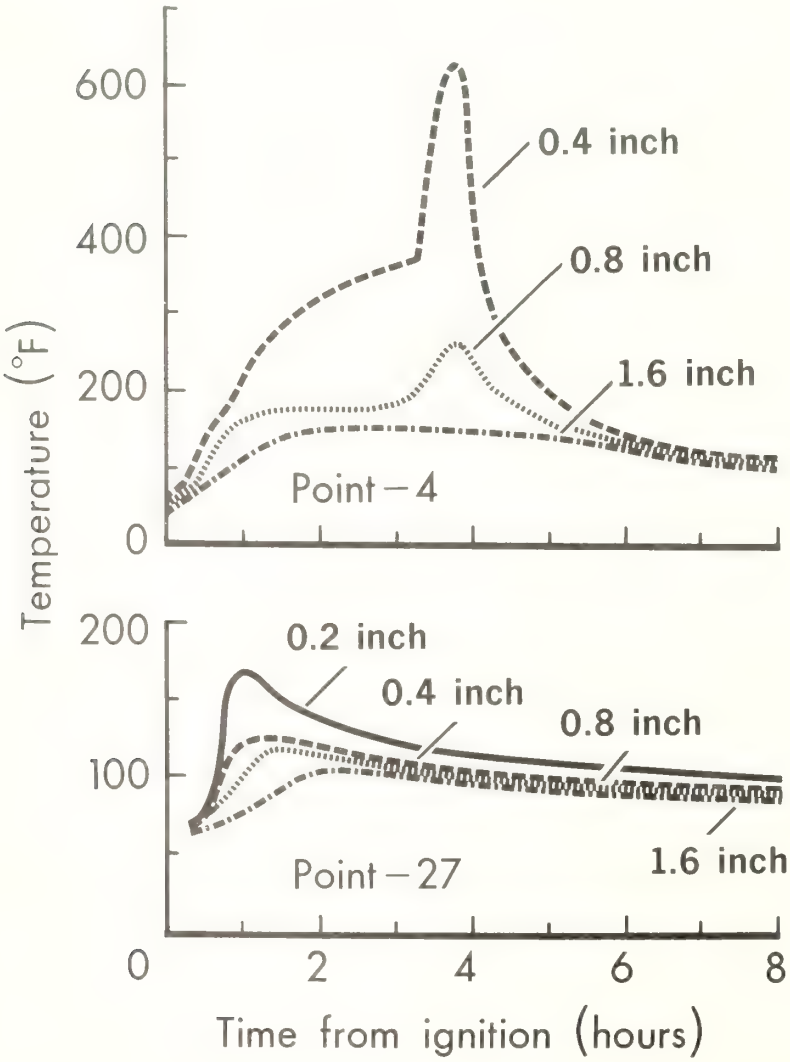

Figure 11.--Soil temperatures recorded at four depths at two points during burning of unit South 8, August 8, 1967.

DISCUSSION

Because establishment of coniferous seedlings, particularly western larch, is enhanced on soil that is free from excessive competition, the successful burn must create receptive seedbed mosaic. Exposure of too much mineral soil seedbed may result in severe overstocking, a problem in many young larch stands. At least three levels of seedbed conditions resulted from 2 years of burning at Miller Creek. Seedbed condition corresponded to the date an area was burned and to the moisture content of the soil.

1.--The first three 1967 burns and nearly all 1968 burns exposed little mineral soil. Usually, litter and duff were not completely burned. Soil water was high and root mortality was low, confirmation that soil temperatures seldom reached the lethal level, especially below 2 inches in depth. Sprouting began within 2 weeks after burning in June, July, and August, and emergent species will grow rapidly and compete with new tree seedlings for light and moisture.

2.--The 1967 wildfire consumed most of the duff on burned units. Postfire soil water was low. These units had little root survival because soils commonly reached lethal temperatures as deep as 4 inches. Occasional sprouting occurred in early September on these areas.

3.--Distribution of exposed mineral soil on units burned in October 1967 was spotty and was limited to areas that sustained high soil temperatures. Frequent rains increased soil water during the period these blocks were burned. Heat penetration was highly variable between areas, particularly on the first burns, where some killing temperatures reached as deep as 4 inches after the fall rains.

APPLICATIONS

These results suggest that if natural regeneration is to be limited by regulating the amount of mineral soil exposed, then prescribed burning must be timed with duff and soil moisture. The best seedbeds on south-, east-, and west-facing slopes apparently resulted from the October 1967 fires. Data are lacking as to when the most root mortality would have resulted on north-facing slopes, but summer burning before the fall rains begin probably will be required.

Stocking control becomes less of a problem when artificial regeneration is used to renew a stand. Lightly to heavily burned seedbeds can be planted or spot seeded without fear of overstocking. These methods also permit selection of microsites where competition is minimized. Based on chance, natural or broadcast seeding offers no such choice. Planting allows the greatest flexibility in seedbed preparation since vigorous, well-planted growing stock initially has a 1- to 3-year growth advantage over newly germinated seedlings.

LITERATURE CITED

Baver, L. D.
1959. Soil physics. 34th ed. John Wiley and Sons, New York.

Beadle, N. C. W.
1940. Soil temperatures during forest fires and their effect on the survival of vegetation. J. Ecol. 28(2):180-192.

Beaufait, William R.
1966. An integrating device for evaluating prescribed fire. For. Sci. 12(1):27-2

Daubenmire, R.
1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearii on concepts of vegetation classification. Ecol. Monogr. 22(2):301-330.

Daubenmire, R., and Jean B. Daubenmire.
1968. Forest vegetation of eastern Washington and northern Idaho. Wash. Agric. Exp. Stn. Tech. Bull. 60, 104 p.

Hare, Robert C.
1961. Heat effects on living plants. U.S. For. Serv. Occas. Pap. 183, 32 p.

Hare, Robert C.
1965. Chemical test for fire damage. J. For. 63(12):939.

Jensen, C. E.
1973. Matchacurve-3, multiple-component and multidimensional mathematical models for natural resource models. USDA For. Serv. Res. Pap. INT-146, 42 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Jensen, C.E., and J. W. Homeyer.
1970. Matchacurve-1 for algebraic transforms to describe sigmoid- or bell-shaped curves. USDA For. Serv., Intermt. For. & Range Exp. Stn., Ogden, Utah 84401. 22 p.

Jensen, C. E., and J. W. Homeyer.
1971. Matchacurve-2 for algebraic transforms to describe curves of the class X^n. USDA For. Serv. Res. Pap. INT-106, 39 p. Intermt. For. and Range Exp. Stn Ogden, Utah 84401.

Steele, Robert W., and Robert C. Henderson.
1967. A simple technique for placing cambium temperature sensors and for determi ing tissue mortality in young trees. Mont. For. and Conserv. Exp. Stn. Re Note 15, 2 p.

Van Wagner, C. E.
1970. Temperature gradients in duff and soil during prescribed fires. Dep. Fisheries and Forestry, Ottawa, Canada, Bi-Mon. Res. Notes 26(4):42.

Van Wagner, C. E.
1972. Duff consumption by fire in eastern pine stands. Can. J. For. Res. 2(1):34-39.

APPENDIX

Formulas used to develop surfaces shown in figures 6, 7, and 10 and the curve nown in figure 8.

Figure 6

$$\text{bot mortality, percent } (\widehat{RM}) = 0.99523\ YP \left\{ \frac{e^{-\left|\frac{\frac{(100 - PW)}{100} - 1}{1 - I}\right|^{2.8}} - e^{-\left(\frac{1}{1 - I}\right)^{2.8}}}{1 - e^{-\left(\frac{1}{1 - I}\right)^{2.8}}} \right\}$$

nere:

$$YP = 31 + 2.6191 \times 10^{-5} (WL)^{1.95} + 38.07\ e^{-\left|\frac{\frac{(WL)}{1300} - 1}{0.2}\right|^{3}}$$

$$I = 0.65 - 8.7172 \times 10^{-15} (WL)^{4.2}$$

WL = Water loss (percent), $0 \leq WL \leq 1300$

PW = Preburn soil water (percent), $0 \leq PW \leq 100$

Figure 7

$$\text{Soil water loss, percent } (\widehat{SWL}) = (YP/(85)^{N})\ (100\text{-}PB)^{N}\ (0.96262)$$

nere:

$$YP = .0096473\ (CWL)$$

$$N = 2.65 - 5.223 \times 10^{-6} (CWL)^{1.75}$$

PB = Preburn soil water (percent), $15 \leq PB \leq 100$

CWL = Can water loss (g), $0 \leq CWL \leq 1300$

Figure 8

$$\text{Duff reduction, percent } (\widehat{DR}) = 100 - 63.772\, e^{-\left|\frac{\frac{MC}{220} - 1}{0.7}\right|^{8}}$$

where:

MC = Duff moisture content, $0 \leq MC \leq 220$

Figure 10

$$\text{Depth, inches } (\hat{D}) = \left(\frac{YP}{(75)^{N}}\right) (100-PW)^{N} (0.97118)$$

where:

$$YP = 1.72906\, e^{-\left|\frac{\frac{(CWL)}{1300} - 1}{0.63}\right|^{2.2}} - 0.10906$$

$$N = 4.0 - 1.5\, e^{-\left|\frac{\frac{(CWL)}{1300} - 1}{0.4}\right|^{4.2}}$$

PB = Preburn soil water (percent), $15 \leq PB \leq 100$

CWL = Can water loss (g), $0 \leq CWL \leq 1300$

SHEARER, RAYMOND C.

1975. Seedbed characteristics in western larch forests after prescribed burning. USDA For. Serv. Res. Pap. INT-167, 26p., illus. Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.

The effectiveness of prescribed broadcast burning for seedbed preparation during the months of May through October was studied on several 10-acre clearcuts on all aspects in western larch forests of northwest Montana. On north-facing slopes, nearly complete duff reduction only occurred during the summer before heavy rains. Other aspects had a broader time range in which to burn for adequate duff reduction. Spring burns did not significantly decrease this layer on any aspect.

OXFORD: 114.122, 114.154, 232.322.6, 436.

KEYWORDS: prescribed burning, western larch, fire use, seedbed preparation, soil heating, moisture content (soil), duff reduction, root mortality.

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GROWING
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CLEARCUTTING AND BURNING SLASH ALTER QUALITY OF STREAM WATER IN NORTHERN IDAHO

Gordon G. Snyder, Harold L. Haupt, and George H. Belt, Jr.

AUTHORS

GORDON G. SNYDER earned his B.A. degree in chemistry at San Diego State University and his M.S. degree in watershed sciences at the University of Idaho. At present, he is completing his Ph.D. degree in forestry sciences at the University of Idaho. From 1965 to 1971, he did research on chemical instrumentation. Since 1971, he has worked with the USDA Forest Service and the University of Idaho on water quality research projects.

HAROLD F. HAUPT is leader of the Water Quality Management research work unit of the Intermountain Station at Moscow, Idaho. For the past 25 years, he has conducted hydrologic research at Idaho City and Boise, Idaho, and Reno, Nevada. During his career, he has made many contributions to the fields of snowmelt hydrology, logging road erosion, and soil stabilization.

GEORGE H. BELT, JR., is associate professor of forestry, University of Idaho. He earned B.S., M.F., and D.F. degrees from Duke University in 1968. His teaching-research career began at University of Idaho in 1965. Since 1968, he has published several papers on micrometeorology. He has done additional research in hydrologic modeling and planning.

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CLEARCUTTING AND BURNING SLASH ALTER QUALITY OF STREAM WATER IN NORTHERN IDAHO

Gordon G. Snyder, Harold F. Haupt,
and George H. Belt, Jr.

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401
Roger R. Bay, Director

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ABSTRACT

Three cutting units of varying size, soil, and aspect located along streams in the Priest River Experimental Forest in northern Idaho were chosen for evaluation of changes in water quality caused by clearcutting and subsequent burning of slash. Water sampling stations were established on each creek--upstream, downstream, and on the site of clearcut-burned areas. Except for on-site stations, buffer strips of natural vegetation were left along channels to minimize the effects of treatment. Physical and nutrient comparisons between the upstream and downstream stations showed slight increases in electrical conductivity, bicarbonate, sulfate, calcium, and magnesium. Similar comparisons between upstream and the on-site stations revealed significant increases in pH, electrical conductivity, turbidity, suspended solids, bicarbonate, sulfate, potassium, calcium, and magnesium. Nutrients that did not indicate increases for buffer strip comparisons were chloride and sodium. In general, larger increases were observed at the on-site stations, except for one station with a different drainage pattern.

INTRODUCTION

U.S. Senate Subcommittee Hearings (1971) on management of the public land focused on clearcutting of timber and subsequent burning of slash. Two major concerns were the long-term depletion of nutrients from the harvested sites and the resultant changes in stream and lake water quality. Tarrant (1971) addressing the committee pointed out that few studies of nutrient depletion have been made; and that most of these were case histories. Though useful, the resultant information has not provided a good base for extrapolation of variables from one ecosystem to another.

Natural rates of nutrient depletion from forested areas are believed to be relatively low. Likens and others (1967) at Hubbard Creek Experimental Forest in New Hampshire found small, but consistent, amounts of major nutrients leaving undisturbed ecosystems. Low natural rates of nutrient loss were also implied in a study of Montana streams (Weisel and Newell 1970). Similarly Skau and others (1971) reported nutrient export was insignificant in Nevada's Truckee River and other tributary streams draining forested lands.

Studies of such forest practices as roadbuilding, clearcutting, slash burning, and herbicide spraying have provided insight into the types of activities that affect nutrient cycles of ecosystems. Roadbuilding has been monitored since 1962 on the H. J. Andrews Experimental Forest (Rothacher and others 1967) and on the Alsea basin in Oregon (Marston 1967). Both studies suggest that road construction increased nutrient losses immediately after construction, but that total loss was small. Packer (1965) concluded from sedimentation studies in northern Idaho and western Montana that roads which were either poorly drained or too close to streams were a primary cause of water quality deterioration in forests. Fredriksen (1971) reported that cation loss increased to 3.0 times following timber harvest and slash burning in Oregon. Three years after logging, calcium and magnesium concentrations had declined from the high reached the second year after logging to a point approaching prelogging conditions. In forests of the Oregon Coast Range, complete forest removal followed by slash burning temporarily, but significantly, altered the pattern of nutrient loss (Brown and others 1973). Under the soil and revegetation conditions observed in their study, such changes did not degrade water quality with respect to nutrient levels nor did they significantly reduce the productivity of forest soils. Partial clearcutting or patch-cutting under such conditions produced no significant change in water quality.

Cole and Gessel (1963, 1968) examined nutrient movement through a forest soil before and after timber harvest. Even after highly soluble salts (urea and ammonium sulfate, both at 200 lb/acre) were added to the forest floor following cutting, only slight amounts of phosphorus, potassium, and calcium were removed beyond the watering depth. This finding demonstrated the effectiveness of the soil system to absorb elements.

After clearcutting on the Hubbard Brook Experimental Forest (Likens and others 1970), all trees and woody vegetation felled were left in place. The area was treated with herbicides for three successive summers to insure that major vegetation would not be present. During the first year after treatment, streamflow export of all ions tested, except ammonium, sulfate, and bicarbonate, was from 2 to 53 times greater on th deforested watershed. The large nutrient losses were attributed mainly to alteration o the nitrogen cycle by clearcutting and herbicide application. Two years after herbicid use was stopped, nitrate losses had decreased to the level of several other cutover for est areas nearby. The Hubbard Brook study provides information as to the highest nutri ent losses that might be expected if vegetative regrowth is denied.

Summarizing results of earlier studies, Tarrant (1971) concluded:

> ...at least for a short period, removal of vegetation from a forest by any means, results in greater nutrient losses from the ecosystem than if the forest had been left undisturbed. The loss is generally small in comparison to the nutrient supply available from all sources at that site. The rate of loss declines 1 or 2 years after treatment. In considering nutrient loss, it must be understood that even with undisturbed forest cover some nutrients constantly leave the site in streamwater....

CEDAR-HEMLOCK-GRAND FIR ECOSYSTEM

The impact of timber harvesting on the quality of stream water has not been studied in the cedar-hemlock-grand fir ecosystem of the northern Rocky Mountains. As early as 1970, plot results obtained in an eastern extension of the ecosystem, and later reported by DeByle and Packer (1972), indicated a flush of nutrients transported by overland flow and sediment moving down the surface of burned, denuded clearcuts. When compared with unlogged check plots, clearcut plots produced increased amounts of total phosphorus, potassium, calcium, magnesium, and sodium for a period of 3 years after burning. However, in their plot study, measurement of the impact of nutrient-laden material upon stream water was not a consideration.

The present paper describes a stream quality study conducted on the Priest River Experimental Forest in northern Idaho. Physical and chemical components were monitored on three clearcut-burned units. Each unit and its surrounding area represented different drainage patterns. All three patterns are common in the ecosystem. Each unit was isolated from the main channel by a buffer strip of unlogged timber.

The objective was threefold: to evaluate changes in the physical and chemical quality of stream water on and off the clearcut-burned units; to characterize nutrient losses from different drainage patterns; and to determine the effectiveness of buffer strips in controlling sediment and nutrient losses. This study extended for 21 months, from the fall of 1970 through the summer of 1972.

METHODS

Study Sites

General Description

The Priest River Experimental Forest is a 2,577-ha tract in the Idaho Panhandle National Forests north of Priest River, Idaho. Mountainous terrain, with elevations ranging from 671 to 1,798 m, makes up 85 percent of the area. Benton Creek, Canyon Creek, and Ida Creek are the major drainages. The climate is predominantly maritime; 89 cm of precipitation, mostly snow, falls between October and June. Summers are warm and dry. Gross precipitation (a mixture of rain or snow and dry fallout) is collected at Headquarters meteorological station.

Soils of the mountain slopes are underlain by Precambrian metamorphic rock. Predominantly silt loam, the soils were derived from glacial till and are capped by a thick layer of volcanic ash. Soils of the lower benches are associated with silt, clay, and sand in varves and strata. Those on the stream terraces and bottom lands are associated with stratified sand and gravel substrata.

The Experimental Forest is entirely forested except for south-slope "balds," rock outcrops, and some clearcut plots. Major tree species of the ecosystem are western white pine (*Pinus monticola* Dougl.), western redcedar (*Thuja plicata* Donn), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and western larch (*Larix occidentalis* Nutt.). Other forest species present are ponderosa pine (*Pinus ponderosa* Laws.), lodgepole pine (*Pinus contorta* Dougl. var. *murrayana* (Grev. & Balf.) Engelm.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), grand fir (*Abies grandis* (Dougl.) Lindl.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and Engelmann spruce (*Picea engelmannii* Parry).

Benton Creek Site

The 44-ha Benton Creek site has a topography ranging in elevation from 914 to 1,219 m. The Jughandle silt loam soil is deep and well drained, and some rock outcrops occur. South and west aspects support mainly 100-year-old Douglas-fir. Remaining areas support 140-year-old white pine.

This site was clearcut in 1969 and broadcast burned in 1970. The boundary of the clearcut is about 61 m from Benton Creek, leaving a buffer strip of natural tree vegetation. During harvesting, there was no jammer skidding of logs across the creek.

Figure 1.--Benton Creek clearcut and water-quality sampling stations. On-site and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

The Benton Creek clearcut and water-quality sampling stations are shown in figure 1. The control station designated "BENTON ABOVE" is upstream from the Benton Creek clearcut at the Benton Creek stream-gaging weir. The off-site station called "BENTON BELOW" is downstream from the clearcut area. The final sampling site, "BENTON ON," is on the lower edge of the southern aspect of the clearcut. A large portion of the south-facing section of the Benton Creek clearcut drains to this point without benefit of a buffer strip. However, this ephemeral drainage flows only during periods of rapid snowmelt or heavy rainfall.

Water samples were first collected September 28, 1970, from BENTON ABOVE and BENTON BELOW. Subsequent samples were obtained weekly and after each storm until heavy snows started. Sampling was resumed as snowmelt began. Samples were also collected during brief winter periods of snowmelt, when there was flow at the on-site station.

Ida Creek Site

The Ida Creek site consists of approximately 2.6 ha at the headwaters of Ida Creek. Elevation is nearly uniform, 745 m, and topography is level. The soil is a Cabinet silty clay loam. Timber types are larch, Douglas-fir, and white pine. Tractor logging of this site was completed by August 1970, and the remaining slash was windrowed and burned in September 1970. The boundary of the clearcut 61 m above Ida Creek provides an area of undisturbed vegetation to function as a buffer strip.

Figure 2.—Ida Creek clearcut and water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

The Ida Creek clearcut and sampling stations are shown in figure 2. From the stations labeled "IDA ABOVE" to "IDA ON," a low-volume flow from a spring crosses the clearcut without a buffer strip. After IDA ON, the surface flow spreads out, seeps underground, reemerges as the main channel of Ida Creek below the buffer strip and upstream from the off-site station designated "IDA BELOW." Interruption of surface flow from IDA ON to IDA BELOW caused atypical changes in water quality that will be discussed. Water sampling began in October 1970 at all stations. Subsequent samples were taken weekly until snow covered the stations. Sampling was resumed during the snowmelt season.

Canyon Creek Site

The Canyon Creek site, between 762-792 m in elevation, covers approximately 26 ha, of which 23 ha were clearcut and 3 ha partially cut. Three soils occur, Saltese loam, Jughandle silt loam, and Bonner silt loam. The site contained mixed stands more than 100 years old of white pine, cedar, larch, Douglas-fir, spruce, and lodgepole pine. The area was clearcut and burned the fall of 1970. The clearcut is separated from Canyon Creek proper by a buffer strip of about 30 m.

off-site stations are respectively designated "ABOVE," "ON No. 1" and "ON No. 2" and "BELOW."

Canyon Creek clearcut and water-quality sampling stations are shown in figure 5. Control and off-site stations respectively designated "CANYON ABOVE" and "CANYON BELOW" are on Canyon Creek upstream and downstream from the clearcut area. Both stations are separated from the clearcut by the buffer strip. The station named "CANYON ON #1" is near a small spring that emerges in the east central portion of the clearcut. The low-volume flow from the spring crosses the clearcut in a well-defined channel without a buffer strip. The flow enters the buffer strip at the station labeled "CANYON ON #2." The first Canyon Creek water samples were collected from all stations in June 1971. CANYON ON #1 was sampled from the time of snowmelt (March) until the low-flow period of summer (July). CANYON ABOVE, CANYON ON #2, and CANYON BELOW were sampled weekly, except during periods of deep snow cover.

SAMPLE COLLECTION AND ANALYSES

Samples were collected in polyethylene bottles from the free-flowing portion of the streams. Streamwater temperature was measured *in situ*. Because of dilute ionic concentrations and low biological productivity of the streams under study, no preservatives were added to the samples. After collection, samples were frozen until sample analyses were made in the University of Idaho laboratory. Because pH and bicarbonate are very susceptible to changes between time of collection and laboratory analysis, and, particularly, after the sample has been thawed and opened, these tests were performed first on each sample.

Hydrogen ion concentration (pH) and bicarbonate concentration (HCO_3) were determined on a Coleman (model 38) pH meter (Brown and others 1970). In nearly all samples the pH was less than 8.3, eliminating the need to test for carbonate (CO_3).

Electrical conductivity was measured by a conductivity bridge (Brown and others 1970) and correlated for temperature at the time of analysis.

Turbidity of a well-shaken sample was measured by a Hellige Turbidimeter. Filtration for determining filterable solids was done using a 0.45-micron millipore filtration disk (Brown and others 1970). The concentration of ions sorbed on filtrable solids was not determined in this study.

Anions were analyzed as follows: chlorides by the Mohr method (Brown and others 1970); nitrates by an Orion, nitrate-specific ion-electrode with a detection limit near 0.6 mg/ℓ; and sulfates by a turbidimetric method (American Public Health Association, Inc. 1971) utilizing a Spectronic 70 (420 nm) and 50 mm cells. Sodium, potassium, calcium, magnesium, the cations, were determined by atomic absorption spectrophotometer (American Public Health Association, Inc. 1971).

Dissolved oxygen was measured in the field and found to be saturated in all stream samples. This dissolved oxygen level was to be expected due to the free-flowing turbulent nature of these shallow creeks. Tannins and lignins were checked on initial samples and the concentrations were below detection limits (American Public Health Association, Inc. 1971). These tests were excluded from the routine analyses for these reasons.

STATISTICAL METHOD

Two statistical analyses were performed on the data. First, all data for each sampling station were processed by computer with means, variances, and standard errors calculated for each parameter. Second, changes in water quality between selected stations were tested for significance by using a t test for paired differences ($\alpha = 0.05$). When data could not be paired by specific day, they were not used; this resulted in a test of differences based on fewer degrees of freedom. These differences will be referred to as paired data, or paired comparisons.

Because of the short reach between ABOVE and BELOW stations, we assumed that prior to land treatment stream quality was essentially the same at both stations. Thus, if significant increases were detected at the BELOW-site station, the contribution originated on the clearcut-burned area. Statistical tests were based on the hypothesis similar to

electrical conductivity of BENTON ABOVE = electrical conductivity of BENTON BELOW.

Paired comparisons were also tested between ABOVE- and ON-site stations to determine the amount of change in quality of stream water flowing directly off the clearcut-burned area.

Similar procedures were used to evaluate differences between ABOVE stations and precipitation samples.

RESULTS

General Chemistry

Results of this study are organized by chemical groups rather than by location. Comparison of station data in tables 1 and 2 indicates that the three sites are slightly different in respect to some measured water-quality parameters. The "stiff-type" diagrams in figure 4 show average concentrations of ions for each site, illustrating this point. The general shape of the diagrams suggests chemical similarities, but the variation in size indicates concentration differences.

In terms of chemical response, the Benton Creek and Canyon Creek sites reacted similarly and predictably. ON-site stations generally had higher concentrations than ABOVE- or BELOW-site stations. The Ida Creek site was an exception; IDA BELOW usually had the highest ionic concentration.

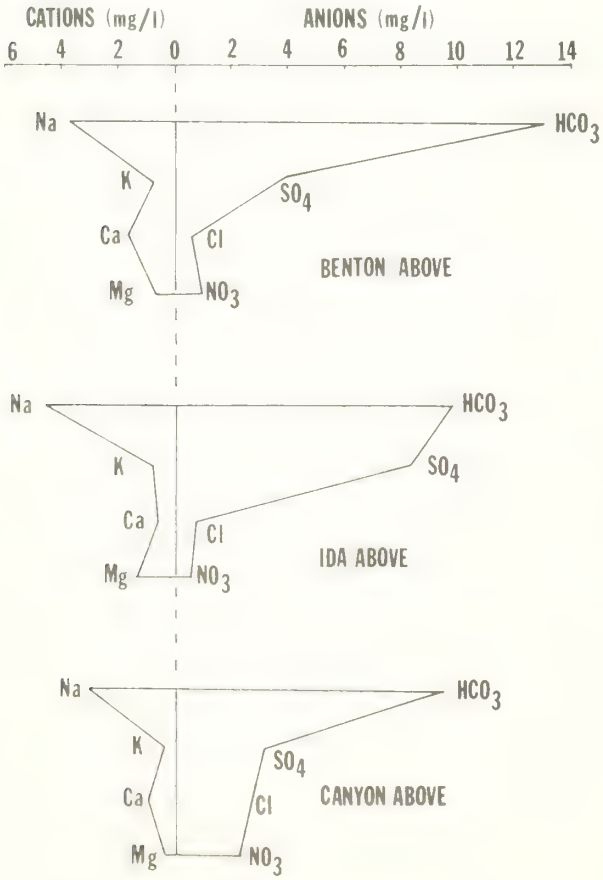

Figure 4.--Average ionic concentrations for the Benton, Ida, and Canyon Creek control (ABOVE) water sampling sites.

Table 1.--[illegible] parameters

STATION/ Parameters	pH	[illegible]	[illegible]	[illegible]
BENTON ABOVE				
Number of samples	78	76	66	
Mean	7.8	[illegible]	[illegible]	4.6
Variance	0.28	170.	0.49	65.3
Standard error	0.06	1.50	0.09	[illegible]
BENTON ON				
Number of samples	16	16	16	
Mean	8.3	140	[illegible]	
Variance	0.24	3780.	148.	3235.
Standard error	0.12	15.4	[illegible]	14.7
BENTON BELOW				
Number of samples	76	76	67	74
Mean	7.9	[illegible]49	[illegible]1.0	4.7
Variance	0.24	99.8	0.72	54.7
Standard error	0.06	1.15	0.10	0.86
IDA ABOVE				
Number of samples	53	54	46	58
Mean	7.4	58	[illegible]1.1	9.0
Variance	0.19	171.	0.60	245.
Standard error	0.06	1.78	0.11	2.06
IDA ON				
Number of samples	55	53	44	[illegible]
Mean	7.3	62	4.9	35.7
Variance	0.15	277.	57.1	[illegible]
Standard error	0.05	2.29	1.14	[illegible]
IDA BELOW				
Number of samples	56	[illegible]	56	55
Mean	7.2	83	3.5	[illegible]
Variance	0.31	740.	740.	[illegible]
Standard error	0.07	3.64	3.64	1.78
CANYON ABOVE				
Number of samples	37	[illegible]	28	37
Mean	7.7	31	0.6	2.7
Variance	0.27	53.2	0.19	3.03
Standard error	0.09	1.20	0.08	[illegible]
CANYON ON #1				
Number of samples	24	24	15	[illegible]
Mean	6.8	40	[illegible].7	[illegible]
Variance	0.32	31.0	1.34	[illegible]
Standard error	0.12	1.14	[illegible]	6.30
CANYON ON #2				
Number of samples	37	37	28	36
Mean	7.3	60	1.6	8.5
Variance	0.16	502.	0.38	28.4
Standard error	0.07	3.68	0.12	[illegible]
CANYON BELOW				
Number of samples	37	[illegible]	28	
Mean	7.5	34	0.8	3.9
Variance	0.19	81.2	0.38	36.1
Standard error	0.07	1.48	0.12	[illegible]
PRECIPITATION				
Number of samples	20	20	18	20
Mean	6.8	24	8.9	21.8
Variance	0.09	240.	42.2	[illegible]
Standard error	0.07	3.47	1.53	3.28

Table 2.--Statistical data from each sampling station for chemical concentrations in water samples

STATIONS. Measurements	Bicarbonate ($CaCO_3$)	Sulfate	Chloride	Nitrate[1/]	Sodium	Potassium	Magnesium	Calcium
				Mg/ℓ				
BENTON ABOVE								
Number of samples	78	73	72	66	75	74	75	75
Mean	13.1	3.6	0.7	0.9	3.7	0.7	0.6	1.5
Variance	7.41	2.31	0.03	2.55	0.34	0.07	0.06	0.26
Standard error	0.31	0.18	0.02	0.20	0.07	0.03	0.03	0.
BENTON ON								
Number of samples	16	15	15	16	16	16	16	16
Mean	51.4	12.8	0.8	7.9	4.1	1.0	4.8	3.2
Variance	503.	25.3	0.08	49.6	0.26	0.14	8.46	7.88
Standard error	1.30	1.30	0.07	1.76	0.13	0.09	0.73	0.
BENTON BELOW								
Number of samples	76	72	75	69	76	76	76	76
Mean	14.2	3.9	0.6	0.8	3.6	0.7	0.7	1.6
Variance	7.31	2.69	0.04	0.67	0.33	0.03	0.04	0.37
Standard error	0.31	0.19	0.02	0.10	0.07	0.02	0.02	0.
IDA ABOVE								
Number of samples	53	57	57	50	60	60	60	60
Mean	9.8	8.5	0.7	0.6	4.6	0.9	1.4	0.8
Variance	2.02	6.64	0.09	0.41	0.72	0.14	0.26	0.12
Standard error	0.20	0.34	0.04	0.09	0.11	0.05	0.07	0.
IDA ON								
Number of samples	53	55	47	44	54	54	54	54
Mean	11.5	10.3	0.8	0.8	4.8	1.7	1.6	0.9
Variance	16.7	16.9	0.13	0.77	0.08	2.40	0.54	0.39
Standard error	0.56	0.56	0.05	0.13	0.14	0.21	0.10	0.
IDA BELOW								
Number of samples	56	57	55	47	57	57	57	57
Mean	21.6	8.2	0.7	0.7	4.6	1.0	2.3	2.2
Variance	64.6	34.5	0.16	0.65	0.85	0.16	0.95	1.62
Standard error	1.07	0.78	0.06	0.12	0.12	0.05	0.13	0.
CANYON ABOVE								
Number of samples	37	36	36	29	37	37	37	37
Mean	7.7	3.1	0.7	0.4	3.1	0.5	0.4	1.0
Variance	0.27	3.00	0.05	0.35	0.94	0.01	0.02	0.07
Standard error	0.09	0.29	0.04	0.11	0.16	0.02	0.02	0.
CANYON ON #1								
Number of samples	24	24	22	21	24	24	24	24
Mean	10.8	4.5	0.7	0.4	3.4	0.6	0.5	1.4
Variance	2.31	2.17	0.03	0.65	0.24	0.06	0.02	0.13
Standard error	0.31	0.30	0.04	0.18	0.10	0.05	0.03	0.
CANYON #2								
Number of samples	37	37	34	28	37	37	37	37
Mean	14.2	4.3	0.8	0.4	4.0	0.8	1.1	2.3
Variance	31.3	2.45	1.38	0.54	0.25	0.21	0.21	0.51
Standard error	0.92	0.26	0.20	0.14	0.08	0.08	0.08	0.
CANYON BELOW								
Number of samples	37	37	37	28	37	37	37	37
Mean	10.1	3.3	0.6	0.2	3.2	0.5	0.5	1.2
Variance	4.83	2.85	0.07	0.06	0.68	0.04	0.04	0.35
Standard error	0.36	0.28	0.04	0.05	0.14	0.03	0.03	0.
PRECIPITATION								
Number of samples	20	19	20	14	17	17	14	17
Mean	6.8	2.4	Trace	0.4	1.1	0.8	0.1	0.4
Variance	0.09	0.87	Trace	0.04	1.20	2.07	0.01	0.03
Standard error	0.07	0.21	Trace	0.05	0.27	0.35	0.02	0.

[1/] These data are subject to question due to minimum detection of 0.6 mg/ℓ for the method of analysis used.

Hydrogen Ion Concentrate (pH)

Alkaline waters characterize streams of the Intermountain Northwest (Streebin and others 1970). This was generally the case in this study, although on all sites, the pH values varied throughout the year. The range of mean pH values never dropped below 6.8 (table 1). However, the pH values may be slightly lower because the samples were frozen before analysis. Benton and Canyon Creek sites show a significant difference in pH within the cut and burned areas, but no changes are evident between ABOVE and BELOW stations (table 3). Ida Creek showed a drop in pH between IDA ABOVE and IDA BELOW that could have resulted from a lack of surface flow from IDA ON to IDA BELOW. The t tests also show a significant difference between all the ABOVE stations and the precipitation (table 4). The pH of the precipitation becomes alkaline by contact with the soils in the watersheds.

Table 3. [illegible]

Station	pH	conductivity			HCO$_3$						
					Mg/ℓ						
BENTON ABOVE vs. BENTON ON	7.9 / 8.3*	134*	1.2 / [illegible]	4.6 / 6.4*	13.3 / 51.4*	12.6*	0.6 / 0.7	0.8 / 7.6*	3.7 / 4.1	0.7 / 1.0*	0.6 / 4.9*	1.6 / 3.2*
BENTON ABOVE vs. BENTON BELOW	7.8 / 7.9	43 / [illegible]	1.0 / 1.0	4.4 / 4.7	[illegible] / 14.3*	4.0*	0.7 / 0.6	0.9 / 0.8	[illegible] / 3.7	0.7 / 0.7	0.6 / [illegible]	1.5 / 1.6*
IDA ABOVE vs. IDA ON	7.4 / 7.3	[illegible] / 62	1.1 / 4.9*	7.1 / [illegible]	9.8 / 11.4*	8.8 / 10.3*	0.7	0.6	4.7 / 4.8	0.9 / 1.7*	1.4 / 1.6*	0.7 / 0.9*
IDA ABOVE vs. IDA BELOW	7.4 / 7.2*	58 / 84*	[illegible] / 3.3*	7.6 / 12.0	9.7 / [illegible]	8.5 / 8.0	0.7	0.6	4.7 / [illegible]	0.9 / 1.0	1.4 / [illegible]	0.7 / [illegible]
CANYON ABOVE vs. CANYON ON #1	7.7 / 6.9*	[illegible] / 40*	0.6 / 1.7*	2.6 / 16.3*	8.5 / 10.9*	3.1 / [illegible]	0.7 / 0.7	0.3 / 0.8*	[illegible] / 3.4*	0.4 / 0.6*	0.5 / 0.3*	0.9 / 1.4*
CANYON ON #1 vs. CANYON ON #2	6.8 / 7.3*	40 / 47*	1.7 / 1.4	10.7 / 7.6	10.9 / 14.2*	[illegible]	0.7 / 0.6*	1.0 / 0.4*	3.4 / [illegible]	0.6 / 0.6	0.5 / [illegible]	1.4 / 2.1*
CANYON ABOVE vs. CANYON BELOW	7.7 / 7.6	31 / 34*	0.6 / 0.8	2.7 / 3.8	9.4 / 10.1	3.1 / [illegible]	0.6 / [illegible]	0.3 / 0.2	3.1 / 3.2	0.5 / 0.5	0.4 / [illegible]	1.0 / 1.2*

*Significant at the 5% level of probability.
1/ These data are subject to question due to minimum detection [illegible] for the method of analysis used.
2/ Not significant because of unusually high variance for BENTON ON.

Table 4.--[illegible] *September 1970 to June 197[illegible]*

Station	pH	Electrical conductivity	Turbidity (SiO$_2$)	Filterable solids	[illegible]	[illegible]	[illegible]	[illegible]	Na	[illegible]	[illegible]	[illegible]
Precipitation at Head-quarters	6.8	24	8.9	21.8	6.8	[illegible]	--2/	[illegible]	[illegible]	[illegible]	0.1	[illegible]
BENTON ABOVE	7.8*	43*	0.9*	4.6*	13.1*	3.6*	0.7	0.9*	3.7*	0.7	0.6*	1.5*
IDA ABOVE	7.4*	58*	1.1*	9.0*	9.8*	8.5*	0.7	0.6	4.6*	0.9	1.1*	0.8*
CANYON ABOVE	7.7*	31	0.6*	[illegible]	7.7*	3.1	[illegible]	0.3	3.1*	0.5	0.4*	1.0*

*Significantly different from precipitation samples at ≥ 0.05 level.
1/ These data are subject to question due to minimum detection of 0.6 mg/ℓ for the method of analysis used.
2/ No statistical comparison.

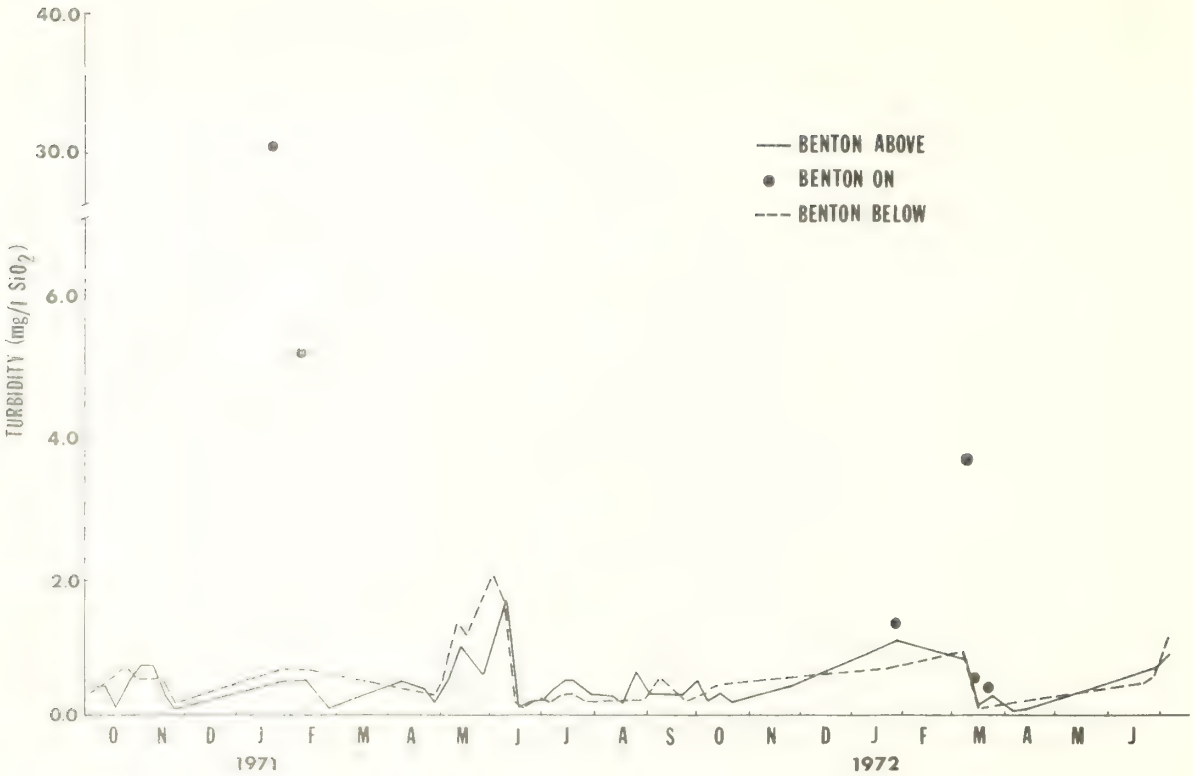

Figure 5.--Weekly average turbidity values for the Benton Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

Turbidity

Turbidity is the optical property of water that causes light to be scattered and absorbed rather than transmitted. Generally, water from study creeks was quite clear; the ABOVE stations' turbidity values ranged around 1 mg/ℓ silicon dioxide (SiO_2) or less. BELOW stations, except IDA BELOW, were not significantly different from ABOVE stations. Statistics in table 3 support the conclusion that increases in turbidity at the ON stations are associated with the clearcut-burned treatment. Turbidity fluctuations for Benton Creek and Ida Creek sites are shown in figures 5 and 6, respectively. The Canyon Creek site (not shown) was similar to the Benton Creek site. The BENTON ABOVE and BENTON BELOW stations show slight increases, but BENTON ON turbidities are almost nine times greater than BENTON ABOVE turbidity values. Data for the Ida Creek site also show an increase, but the decrease in turbidity of the Ida Creek values to previous levels within 6 months is notable.

Filterable Solids

Measurement of filterable solids verifies loss of particulate matter from a watershed (table 5). Concentrations for all the ABOVE and BELOW stations are nonsignificant, whereas ON-site stations show a significant increase. This increase is probably associated with soil disturbance caused by logging and by lack of soil protection after

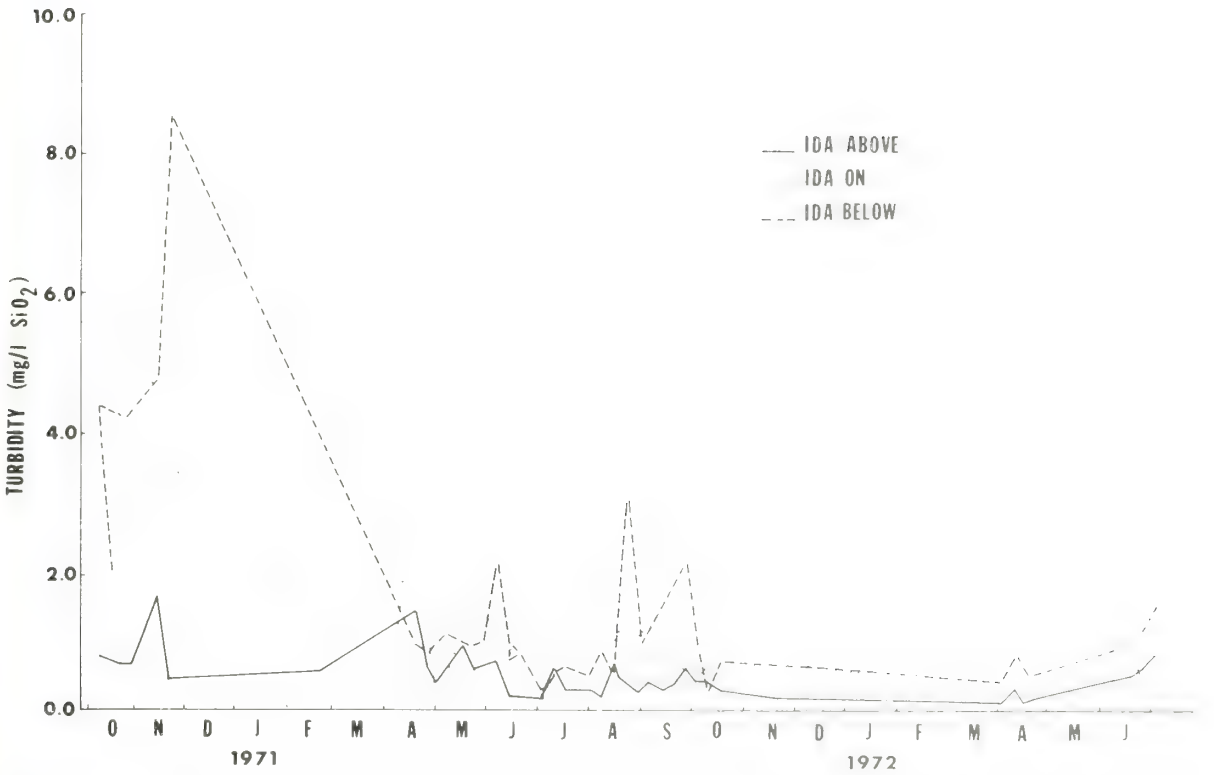

Figure 6.--Weekly average turbidity values for the Ida Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

burning of litter and slash. ON-station increases relative to ABOVE stations were 14, 4, and 6 times greater for Benton, Ida, and Canyon Creeks, respectively.

Of special interest is the high rate of incoming solids detected in the precipitation (table 4). This input to the system is several times greater than natural losses in the stream water.

Electrical Conductivity

Electrical conductivity represents the amount of electrical current a sample of water will conduct. Because conductance is proportional to the concentration of dissolved ions, this test indexes the total concentration of ions present in a sample. Mean electrical conductivity for the ABOVE stations ranges from 27 to 58 μmhos/cm (table 3). Graphs in figures 7, 8, and 9 show natural variation within season. The highest values occurred during periods of low streamflow, except for BENTON ON. These graphs also show greater variability for the ON-site stations. For instance, the average electrical conductivity for the BENTON ON station was three times the average for the BENTON ABOVE station, but the variance increased 40 times. This trend can also be seen for the Ida and Canyon Creek sites, but not to the same degree. Larger variance in the BENTON ON samples is probably due to the limited period of flow which occurs only during rapid snowmelt and heavy rainfall. Significant changes in electrical conductivity are indicated between all the ABOVE and BELOW stations.

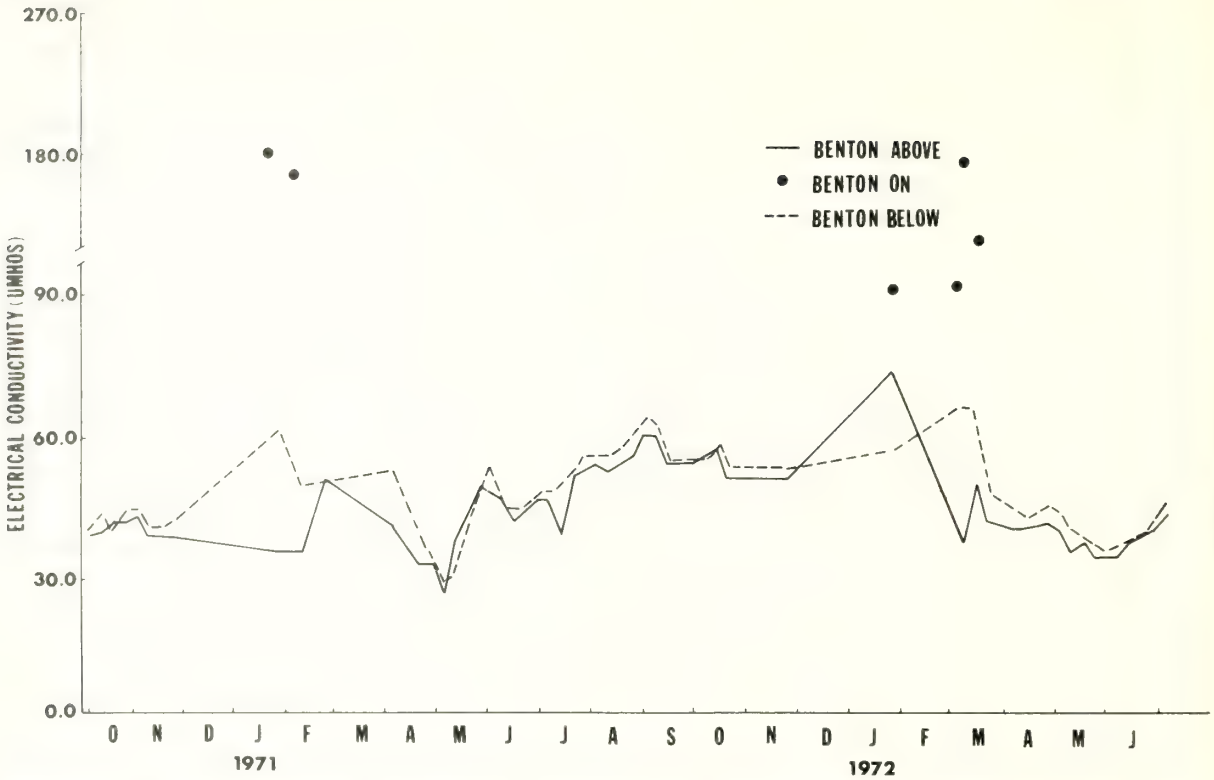

Figure 7.--Weekly average electrical conductivity values for the Benton Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

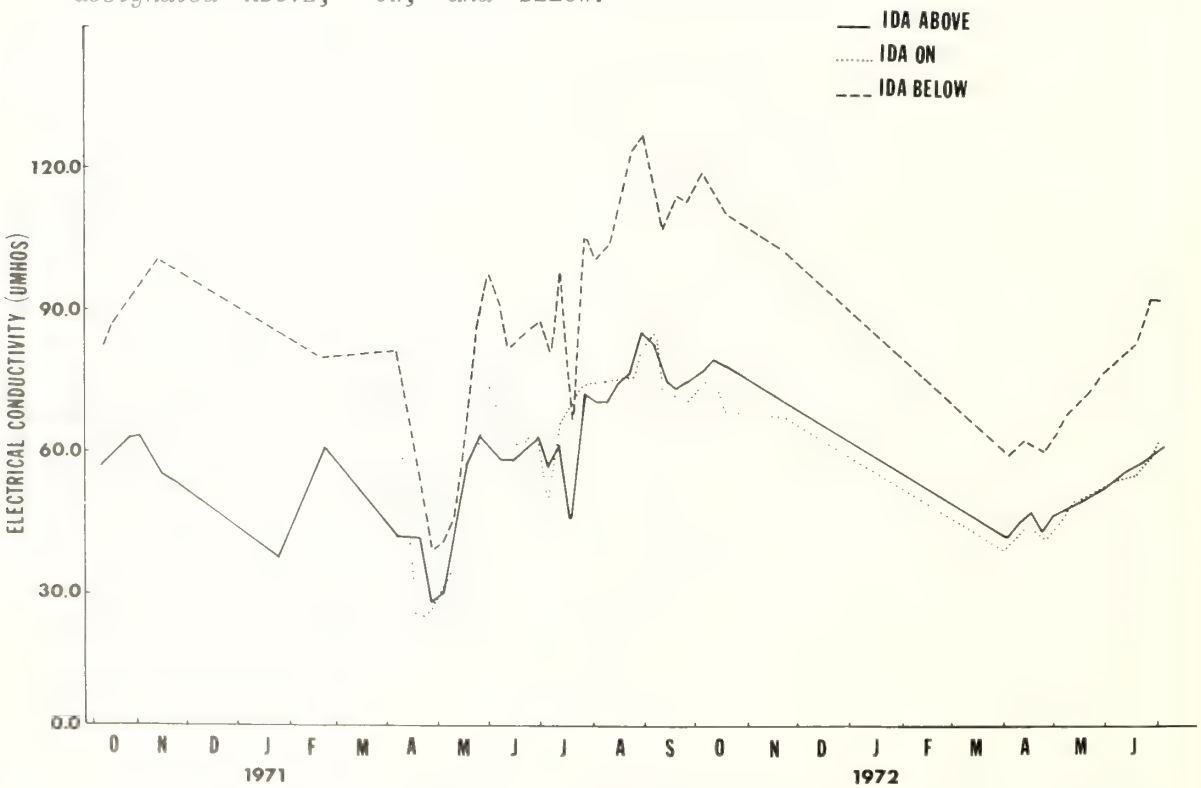

Figure 8.--Weekly average electrical conductivity values for the Ida Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

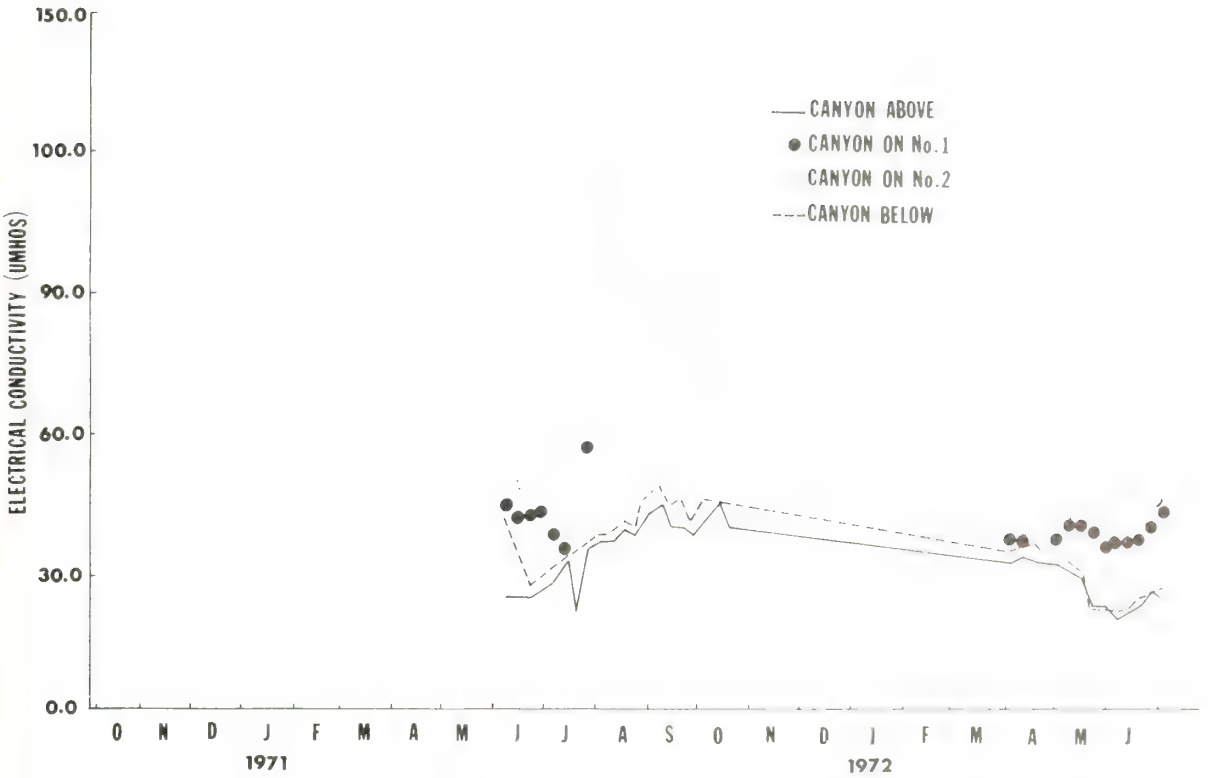

Figure 9.--Weekly average electrical conductivity values for the Canyon Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON No. 1" and "ON No. 2," and "BELOW."

Bicarbonate (HCO_3^-)

Bicarbonate was the most abundant anion in the three basins under study. Mean bicarbonate concentrations in table 3 for BENTON ABOVE and BENTON BELOW are about 13 and 14 mg/ℓ, respectively, but the concentration for BENTON ON is 51 mg/ℓ--an increase of almost four times (fig. 10). CANYON ON #1 also evidences an increase in mean bicarbonate over the CANYON ABOVE station, but the increase was only from 8 to 11 mg/ℓ (fig. 11). The IDA ON and BELOW stations also showed increases over the ABOVE station value of 10 mg/ℓ (fig. 12). But, as was characteristic for the Ida site, the BELOW station was the highest with a value of 22 mg/ℓ, about twice the value of the ABOVE station. The striking result is the increased variance in bicarbonate concentrations for the stations. Variances for the BENTON ON and CANYON ON stations increased 68 and 116 times, respectively, over the ABOVE values. T tests also show all BELOW-station increases to be significant.

The bicarbonate concentration of the precipitation shown in table 4 is significantly less than the baseline bicarbonates of the three ABOVE stations.

Sulfate (SO_4^+)

Next to bicarbonate, sulfate proved to be the second most abundant anion in the stream water. The BENTON ON-site station averaged higher sulfate concentrations than the BENTON ABOVE station. The mean concentration increased about four times from ABOVE to BELOW table 3), but the variance increased more than 10 times (table 2).

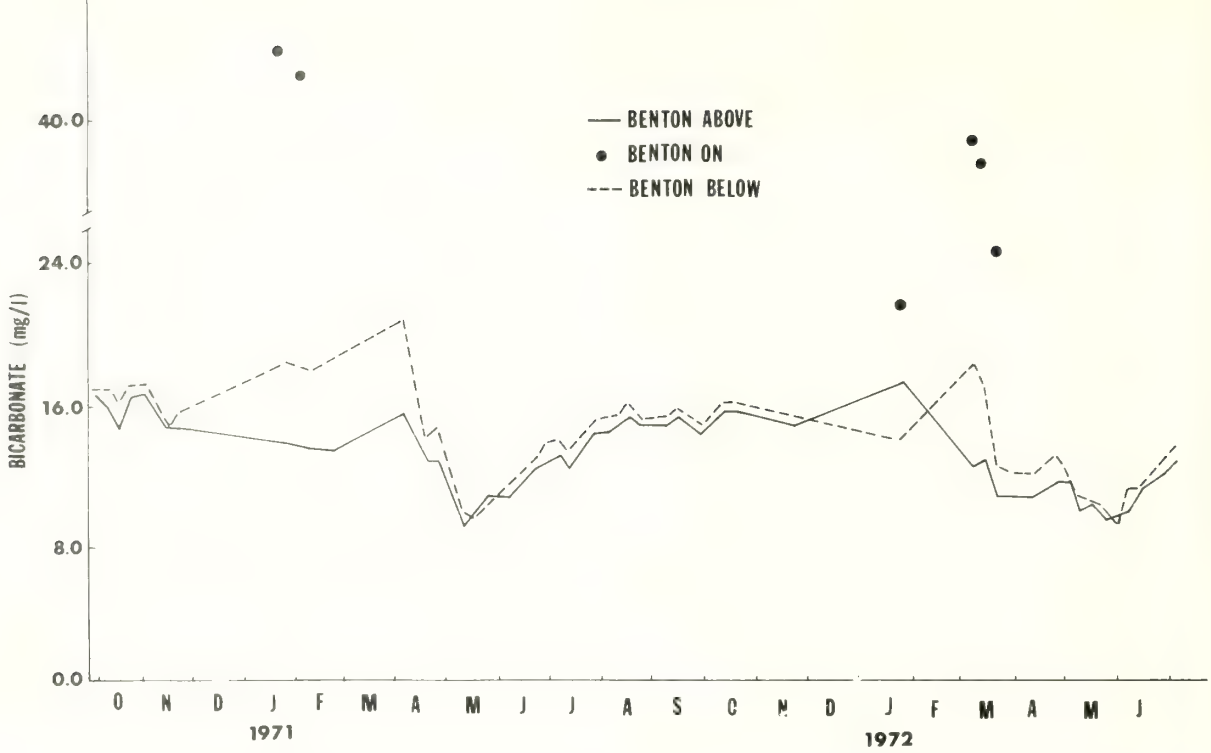

Figure 10.--Weekly average bicarbonate values for the Benton Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

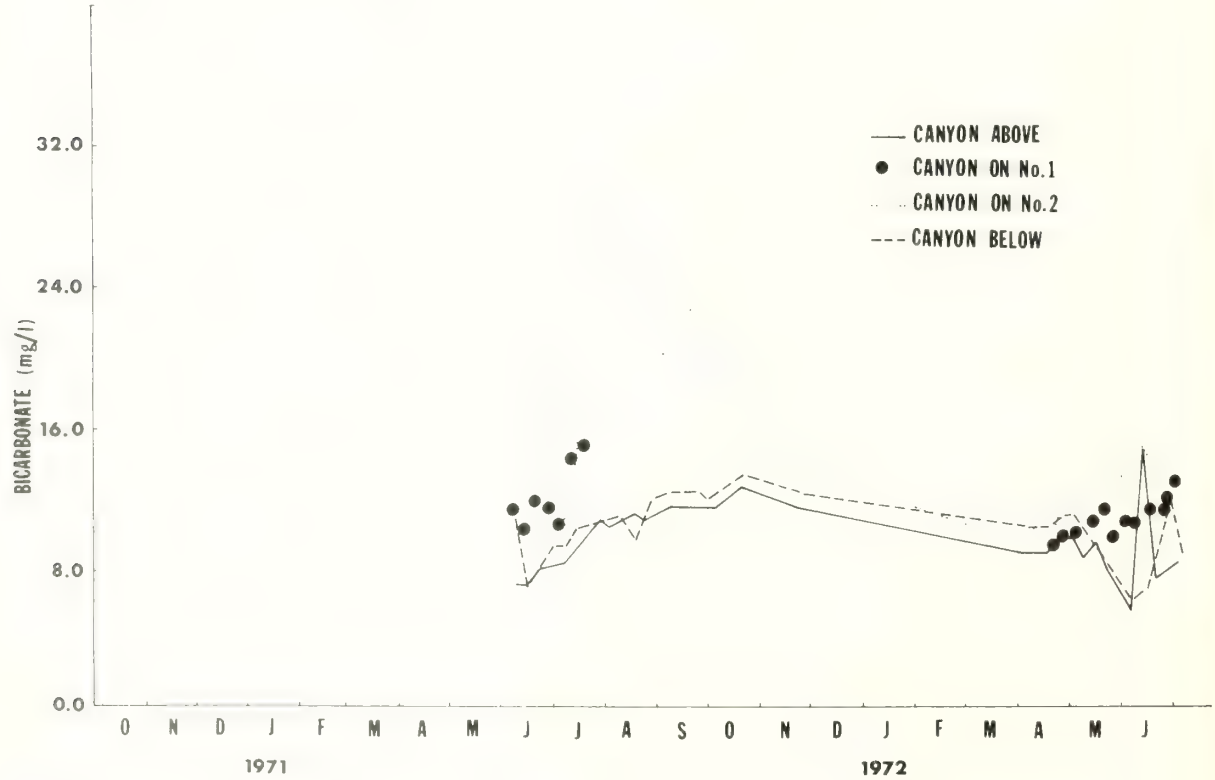

Figure 11.--Weekly average bicarbonate values for the Canyon Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON No. 1" and "ON No. 2, and "BELOW."

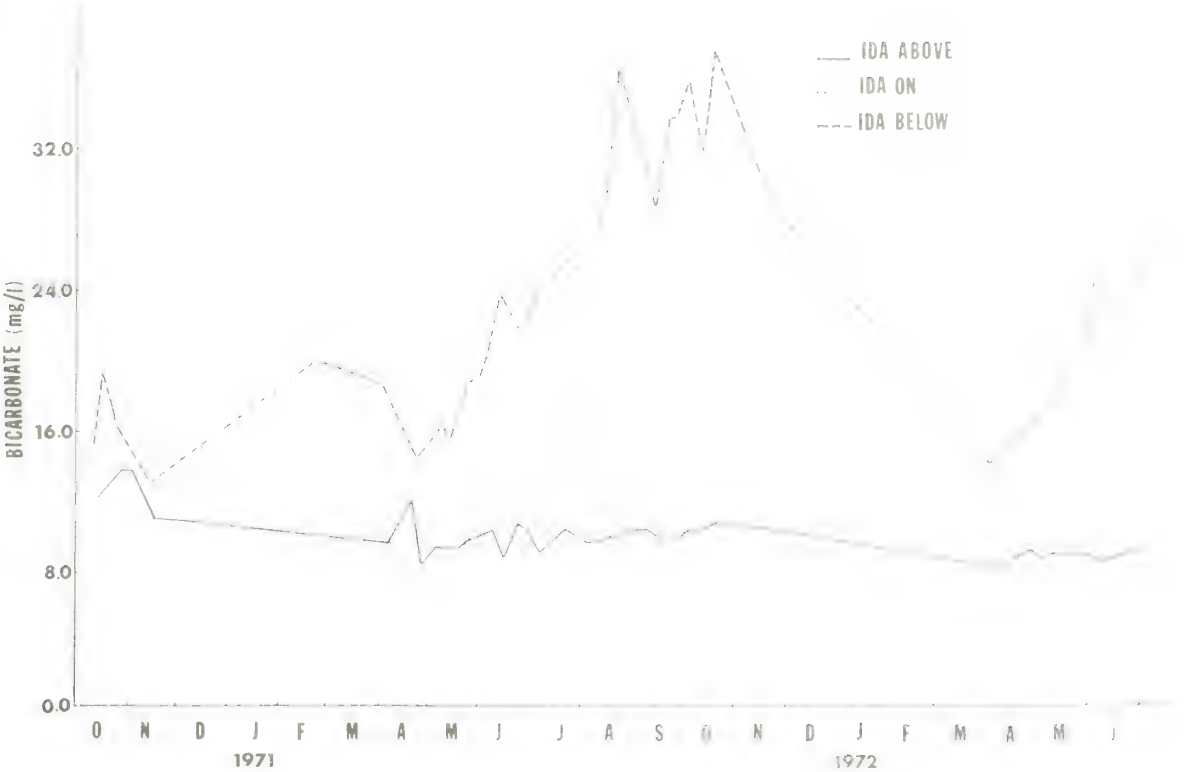

Figure 12.--Weekly average bicarbonate values for the Ida Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

Mean sulfate concentrations for the CANYON on-site stations were [illegible] mately, but the variance dropped slightly, the opposite response from the normal for ON-site stations. The average for IDA ON station shows a slight increase over IDA ABOVE. This increase was not of the same magnitude as that of the other nutrients. IDA BELOW was not significantly different from IDA ABOVE (table 3). The variances showed the usual increase from IDA ABOVE to IDA BELOW, again indicating that the normal range of concentrations of sulfate ions was altered by the clearcut-burned treatment.

Ida Creek sites have a much larger variation and a greater range of sulfate ion concentrations than the Benton Creek site, because of the headwater location of the Ida Creek site (fig. 13 and 14). The Canyon Creek site curves are not shown, but were very similar to those for Benton Creek in figure 13.

Sulfate concentrations in the precipitation averaged over 2 mg/ℓ, roughly 1 to 6 mg/ℓ less than the ABOVE sites (table 4). This concentration was significantly lower than that at the ABOVE stations of Benton and Ida Creeks. CANYON ABOVE station, however, did not show significant differences.

Chloride (Cl^-)

Chloride concentrations did not change with land treatment. The mean concentration for all stations ran less than 1 mg/ℓ, which is close to the detection limit.

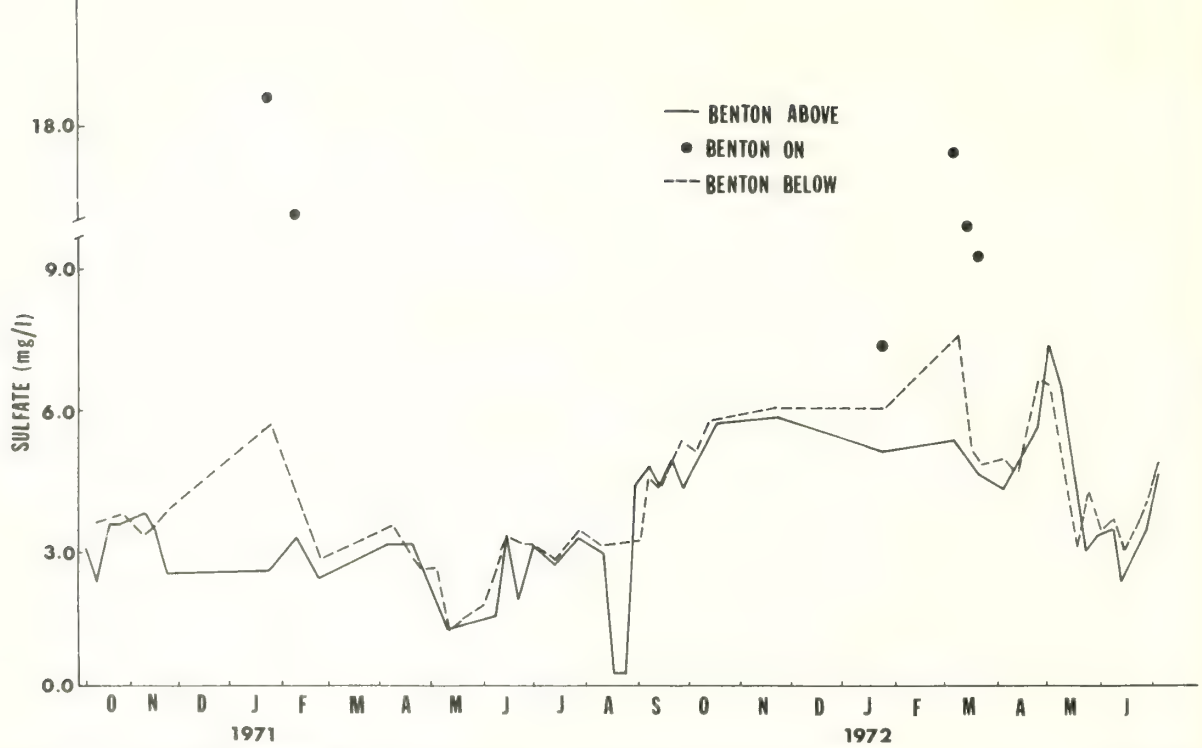

Figure 13.--Weekly average sulfate values for the Benton Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

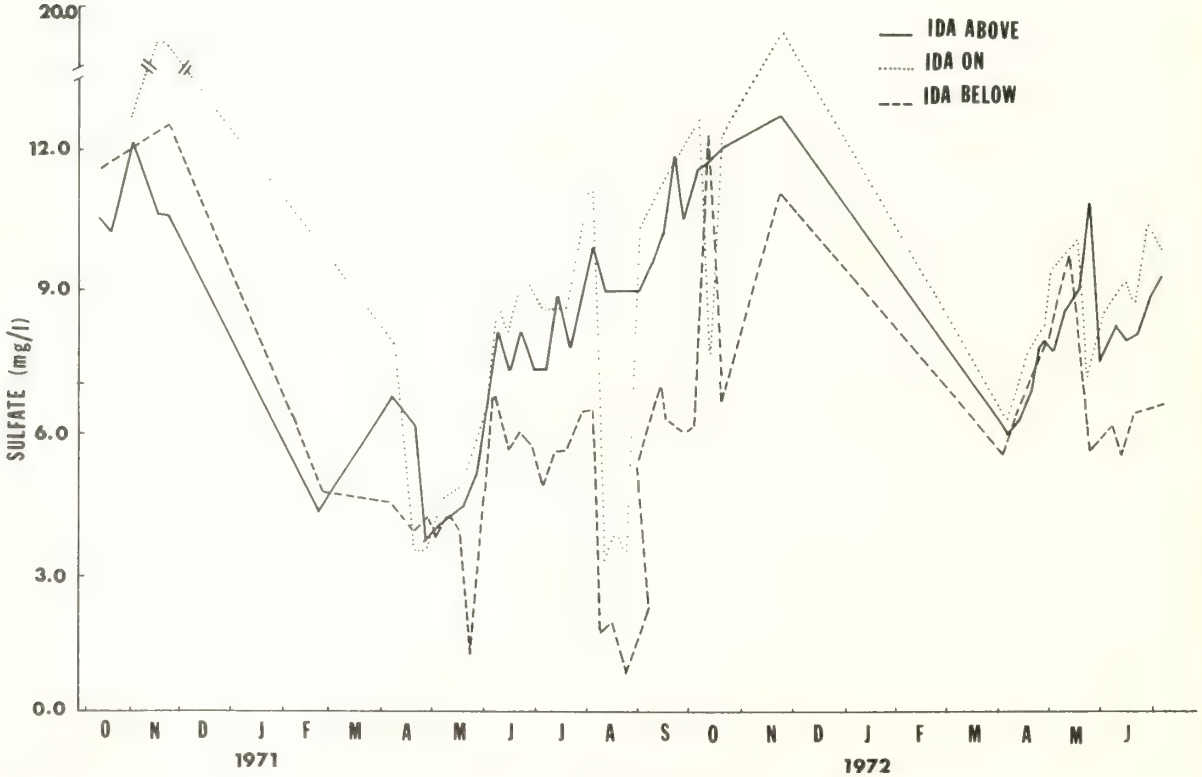

Figure 14.--Weekly average sulfate values for the Ida Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

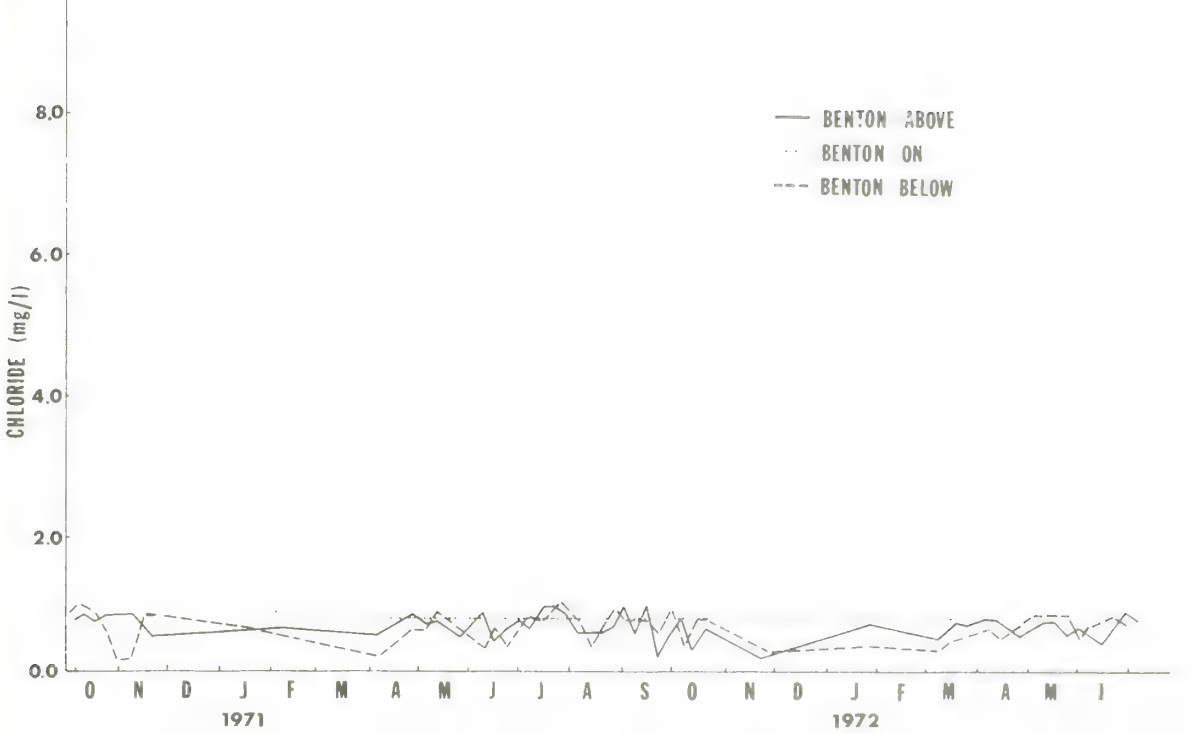

Figure 15.--Weekly average chloride values for the Benton Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

The Benton Creek site (fig. 15) typifies data observed for the other sites. Apparently, clearcutting or burning did not influence the concentration of chlorides. Only trace amounts of chloride were found in the precipitation samples.

Nitrate (NO_3^-)

Nitrate ion concentrations (table 3) averaged less than 1 p/m, except for the BENTON ON-site station. This station averaged 8 mg/ℓ, about eight times the BENTON ABOVE value. Peak concentrations of nitrate for the Benton and Ida Creek sites occurred during periods of rapid snowmelt. Although some peak concentrations of the BELOW stations were two or three times higher than the ABOVE stations, none of the paired comparisons were significant. If logging and burning caused a release of nitrate ions, the amount of nitrate loss was indeed small. Also, except for BENTON, nitrate ion concentrations for the ABOVE stations were not significantly different from such concentrations in precipitation. The reader should be cautioned that all nitrate values are higher than normally expected due to the minimum detection limits (0.6 mg/ℓ) of the nitrate electrode used for analysis.

Sodium (Na^+)

Sodium concentrations changed very little with land treatment (fig. 16, 17, and 18). Mean concentrations for the Benton Creek and Ida Creek sites changed less than .5 mg/ℓ between the ABOVE and ON stations. The only significant change occurred on Canyon Creek (table 3) between the CANYON ABOVE and CANYON #1 stations. Average sodium concentration due to treatment increased less than 1 mg/ℓ, a nonsignificant increase at CANYON BELOW. Sodium concentration in the precipitation was found to be significantly less than the concentration at the three ABOVE stations.

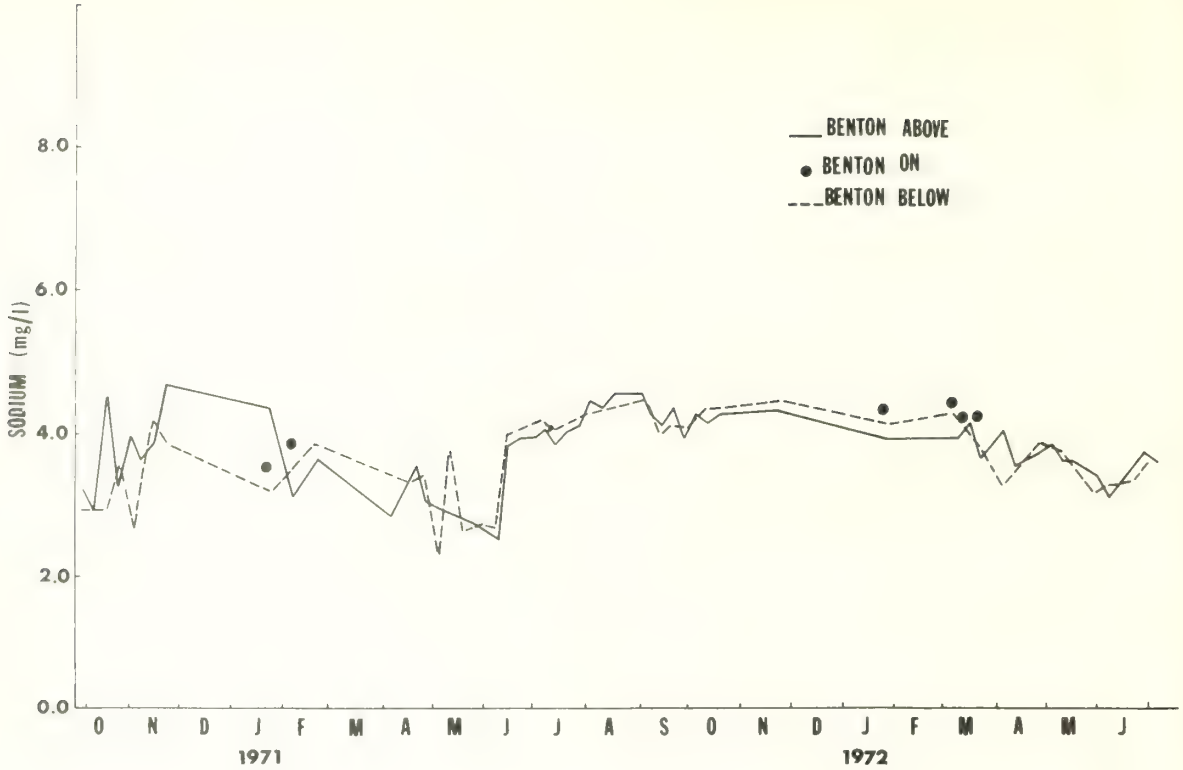

Figure 16.—Weekly average sodium values for the Benton Creek water sampling sites. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

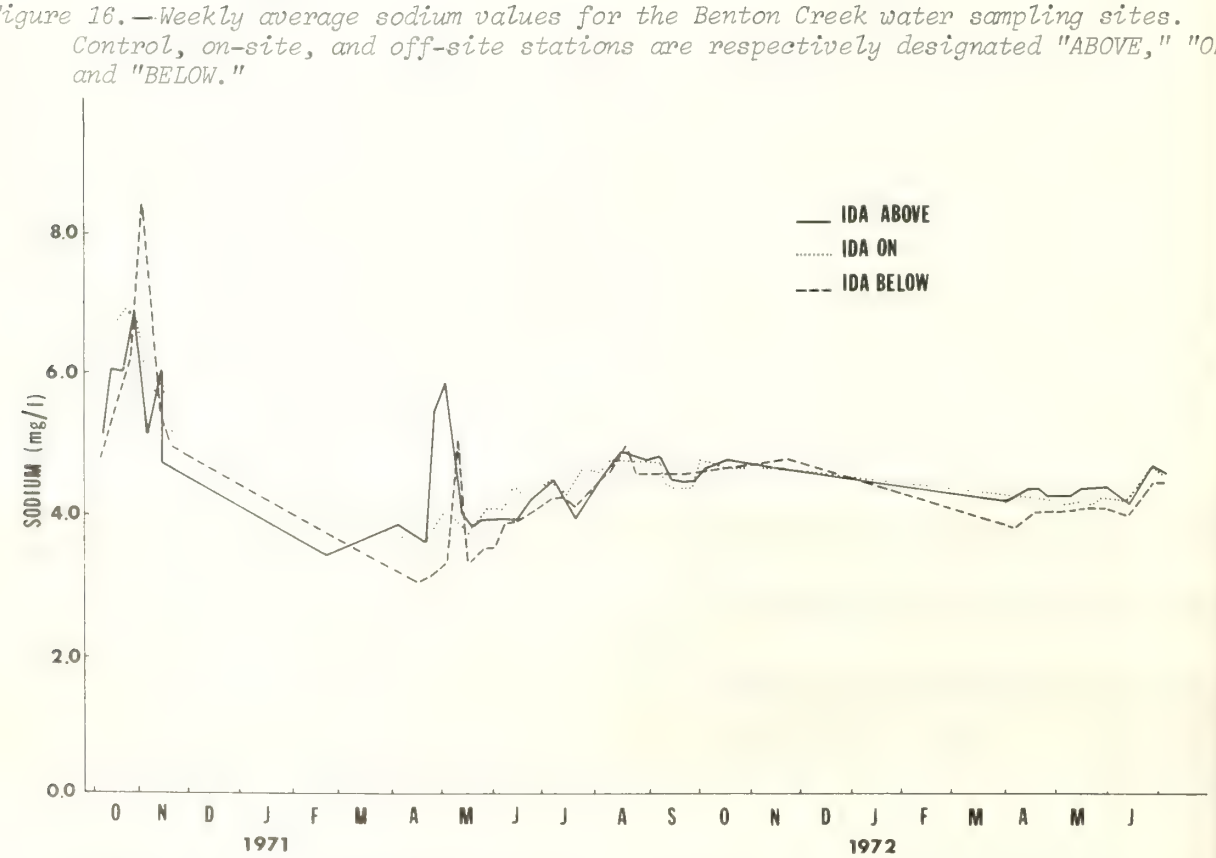

Figure 17.--Weekly average sodium values for the Ida Creek water sampling sites. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

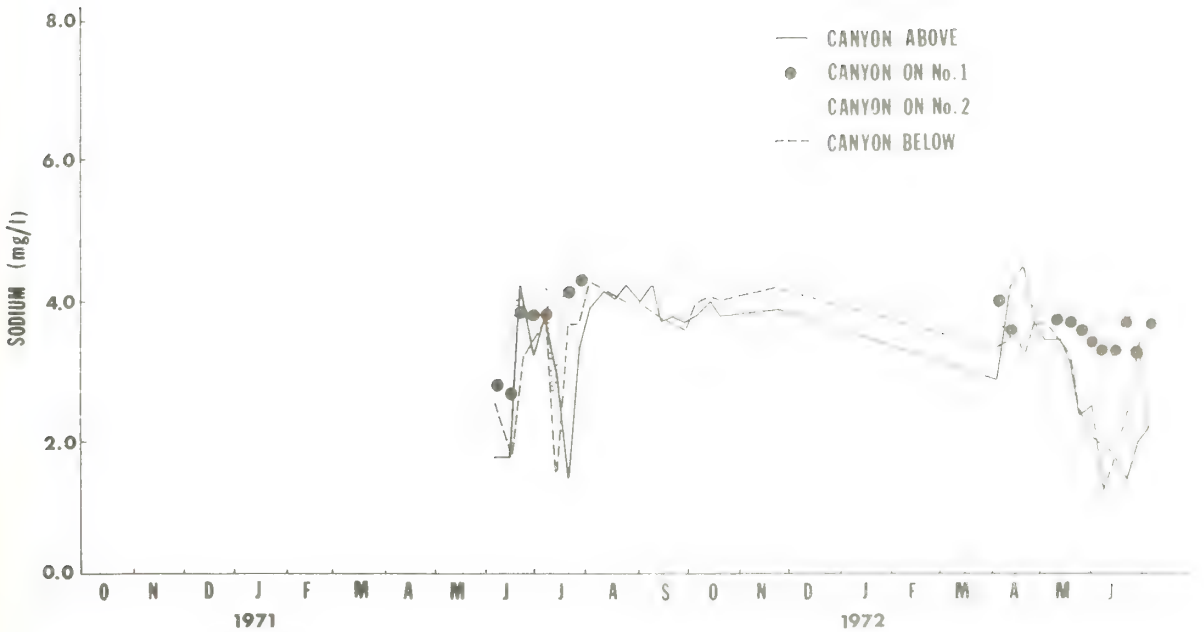

Figure 18.--Weekly average sodium values for the Canyon Creek water sampling sites. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," (No. 1 and No. 2), and "BELOW."

Potassium (K^+)

Potassium increased significantly with land treatment on all three sites between ABOVE and ON stations. However, no significant change occurred between the ABOVE and BELOW stations. Canyon Creek response was similar to that for Benton Creek (fig. 19). On the Ida Creek site, potassium concentration at the ON station rapidly decreased to a normal level (fig. 20). Highest values were observed immediately after logging and burning at the time of fall precipitation, but within 1 year, the concentration had returned to a normal level.

Comparison of potassium concentrations between ABOVE stations and precipitation catch showed no significant difference.

Magnesium (Mg^+)

Magnesium concentrations for the ABOVE and BELOW stations from Benton and Canyon Creek sites have similar averages, less than 1 mg/ℓ, and a variance no greater than 0.06 (fig. 21 and 22). This small variance suggests a low dependence of magnesium concentration on seasonal flows. The Ida Creek site, however, shows more pronounced cyclic variation (fig. 23); average magnesium concentrations and variances increased from the ABOVE to BELOW stations. The variances at the Ida Creek stations were 4 to 40 times the variances of the Benton Creek or Canyon Creek sites.

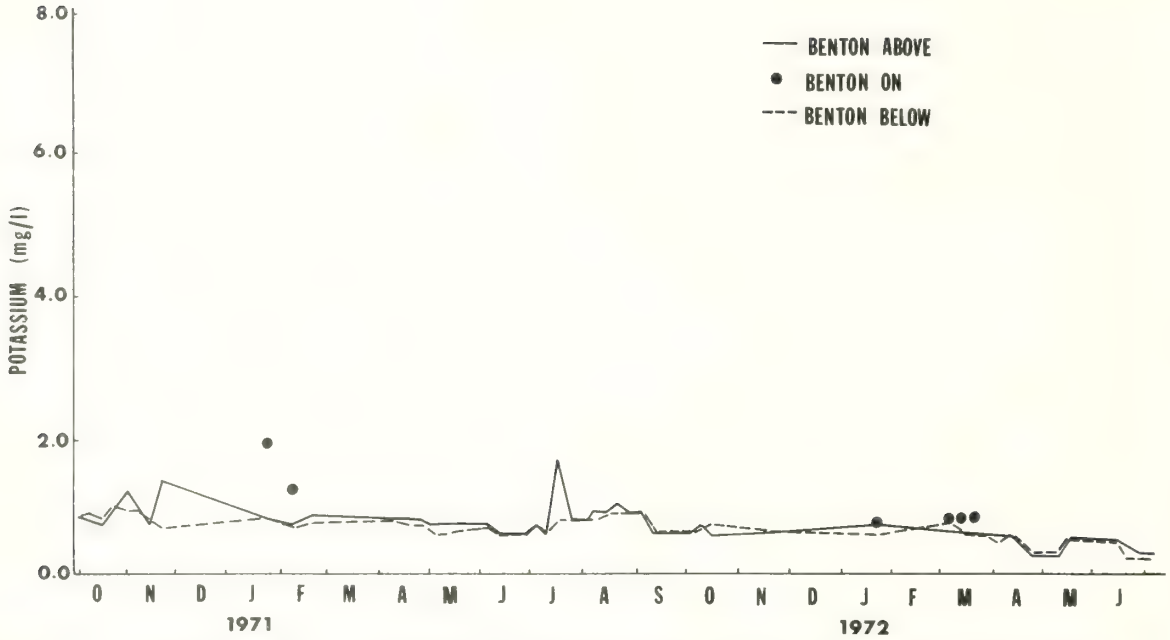

Figure 19.—Weekly average potassium values for the Benton Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

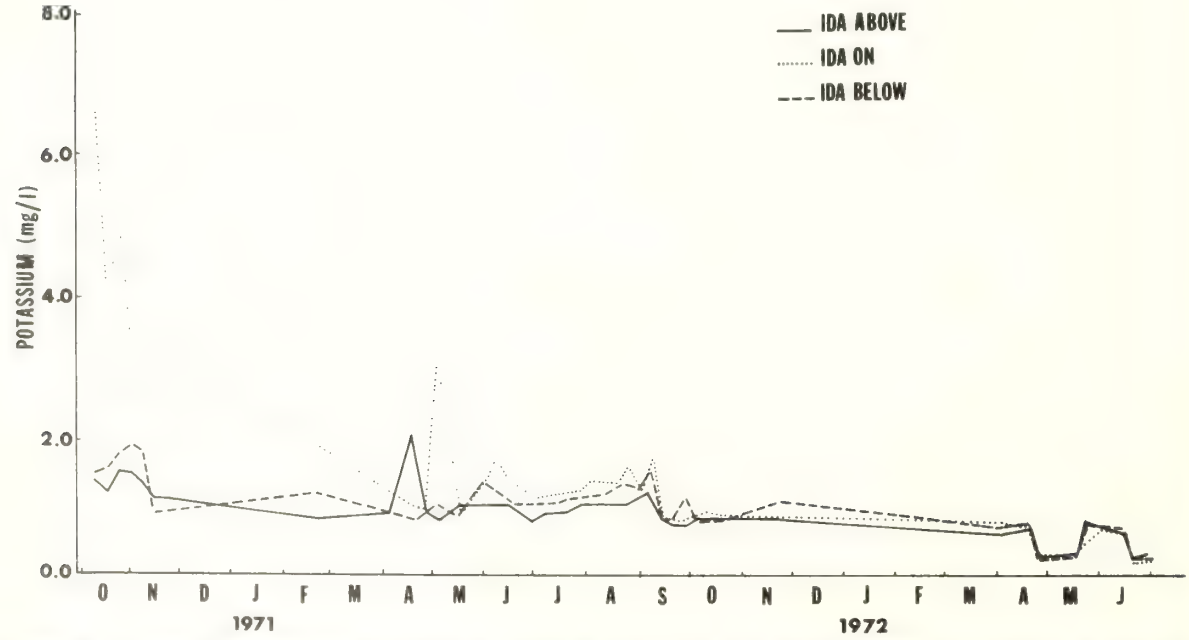

Figure 20.--Weekly average potassium values for the Ida Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

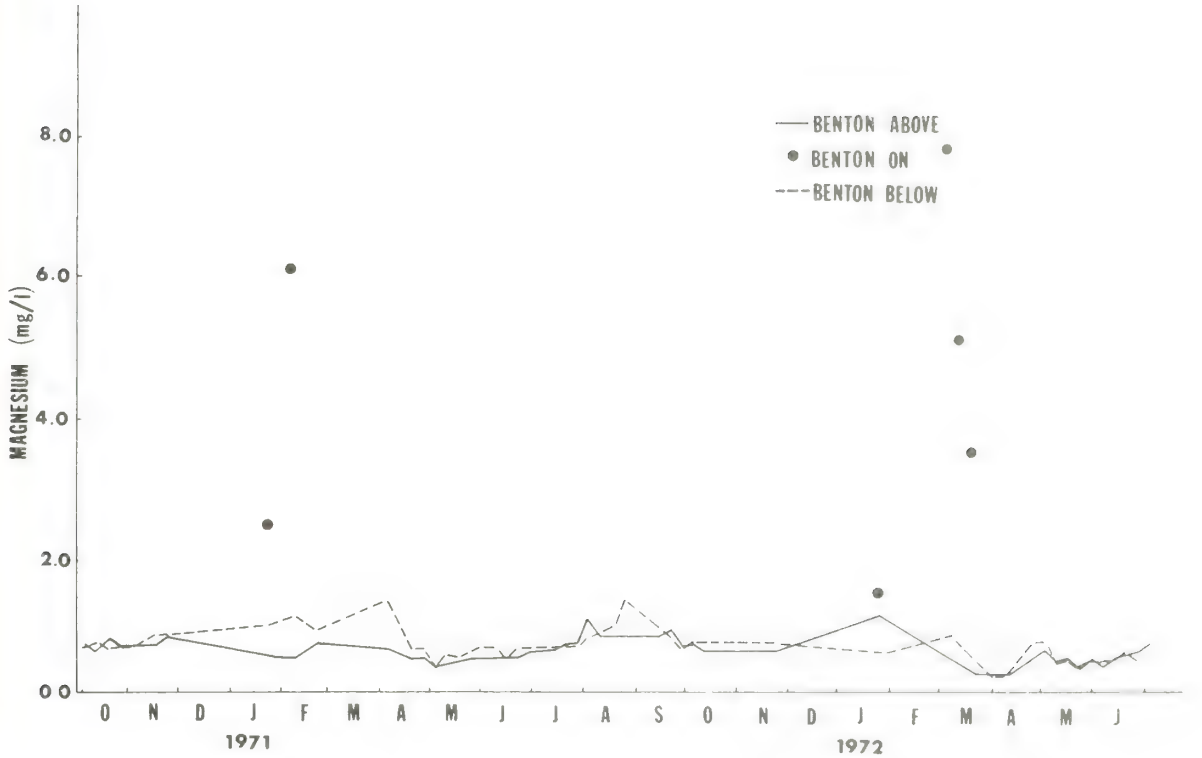

Figure 21.--Weekly average magnesium values for the Benton Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

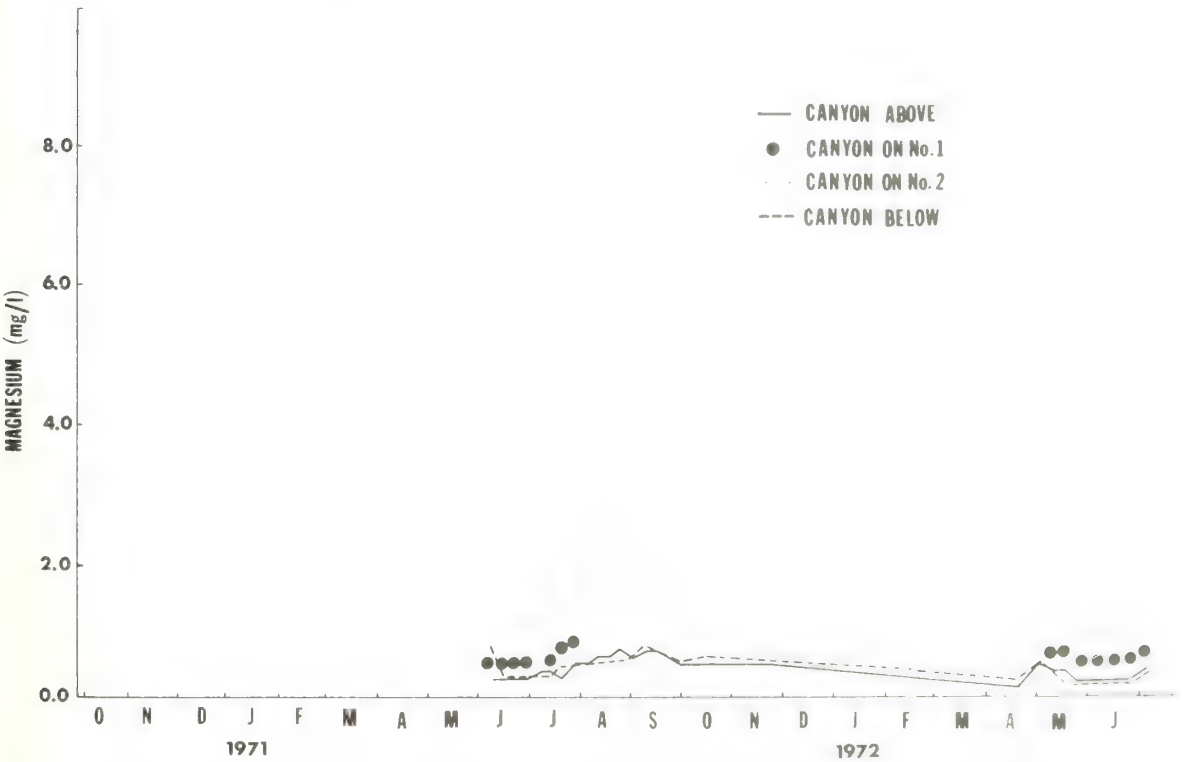

Figure 22.--Weekly average magnesium values for the Canyon Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON" (No. 1 and No. 2), and "BELOW."

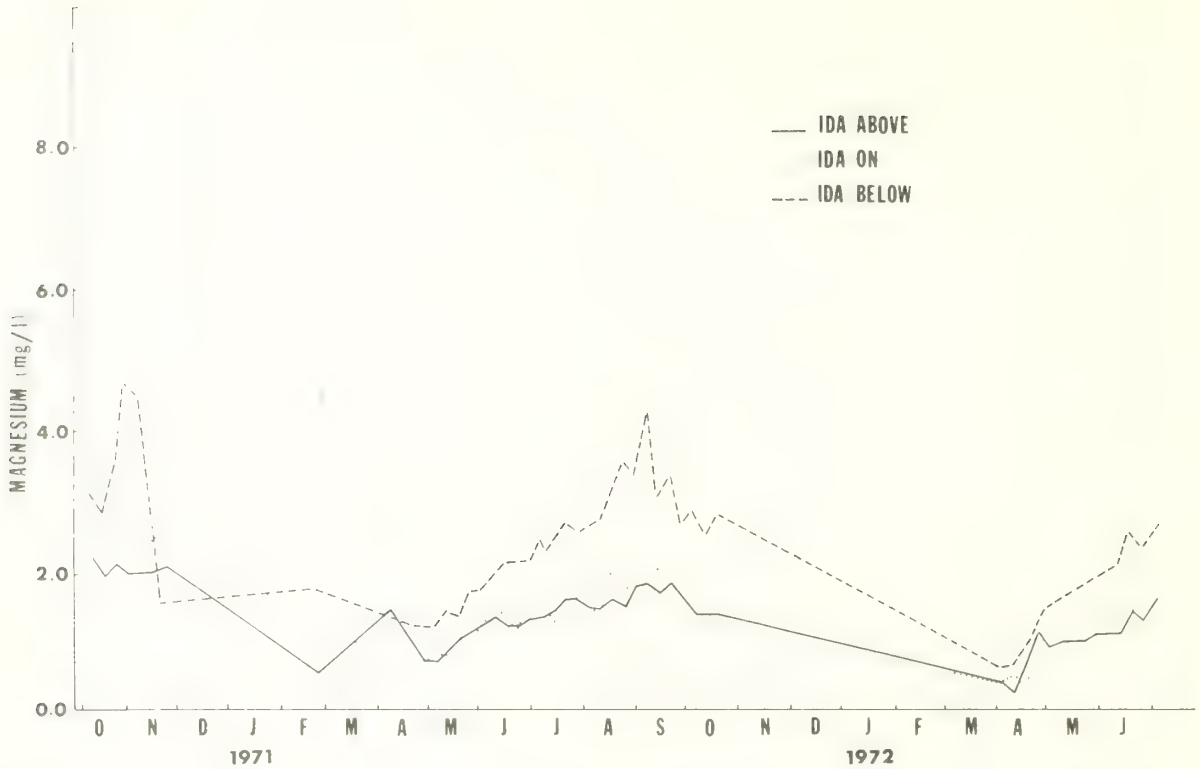

Figure 23.—Weekly average magnesium values for the Ida Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

Magnesium concentrations increased significantly for the ABOVE- and ON-site stations at all three sites. A significant difference exists between the ABOVE and BELOW stations of all sites except Canyon Creek. Magnesium concentration in the precipitation was significantly less than that for the three ABOVE stations.

Calcium (Ca^{++})

Mean calcium concentrations ranged from 1 to 2 mg/ℓ for the ABOVE stations (table 3). Concentrations at the ON-site stations for Benton and Canyon Creeks were twice the ABOVE-site concentrations, but the IDA ON-site concentration was only slightly higher than the IDA ABOVE calcium concentration.

Calcium concentrations show some dependence upon seasonal flows (fig. 24, 25, and 26). However, during low-flow periods, concentrations do not increase as might be expected from previous nutrient results. Instead, calcium values increased during periods of snowmelt and high flow. The concentration differences between the ABOVE and BELOW stations for the high-flow period are most apparent for the Benton and Ida Creek sites. During high flow, the BELOW stations had significantly higher calcium concentrations than did the ABOVE stations. It is difficult to generalize the dependence of calcium on seasonal flow, but it is apparent that calcium can be lost from the clearcut-burned area during periods of high runoff. As with most of the other measured cations, the calcium content of the precipitation was significantly less than that of stream water at ABOVE stations.

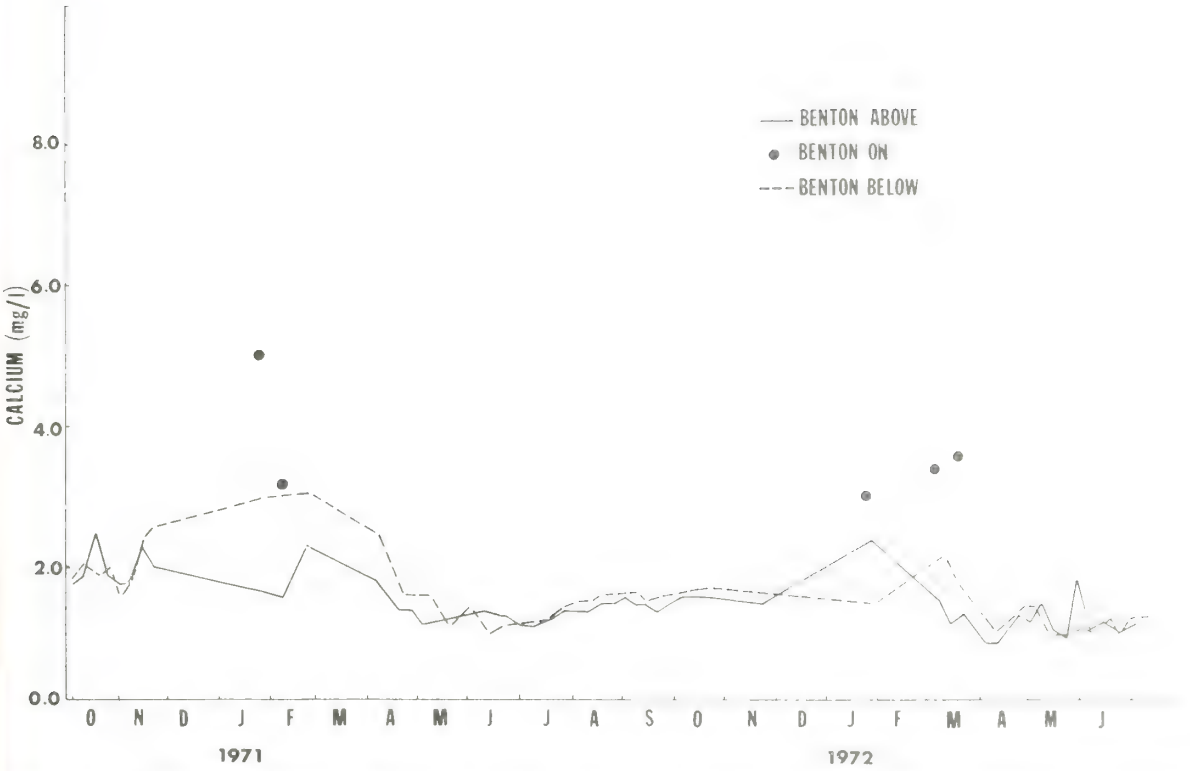

Figure 24.--Weekly average calcium values for the Benton Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

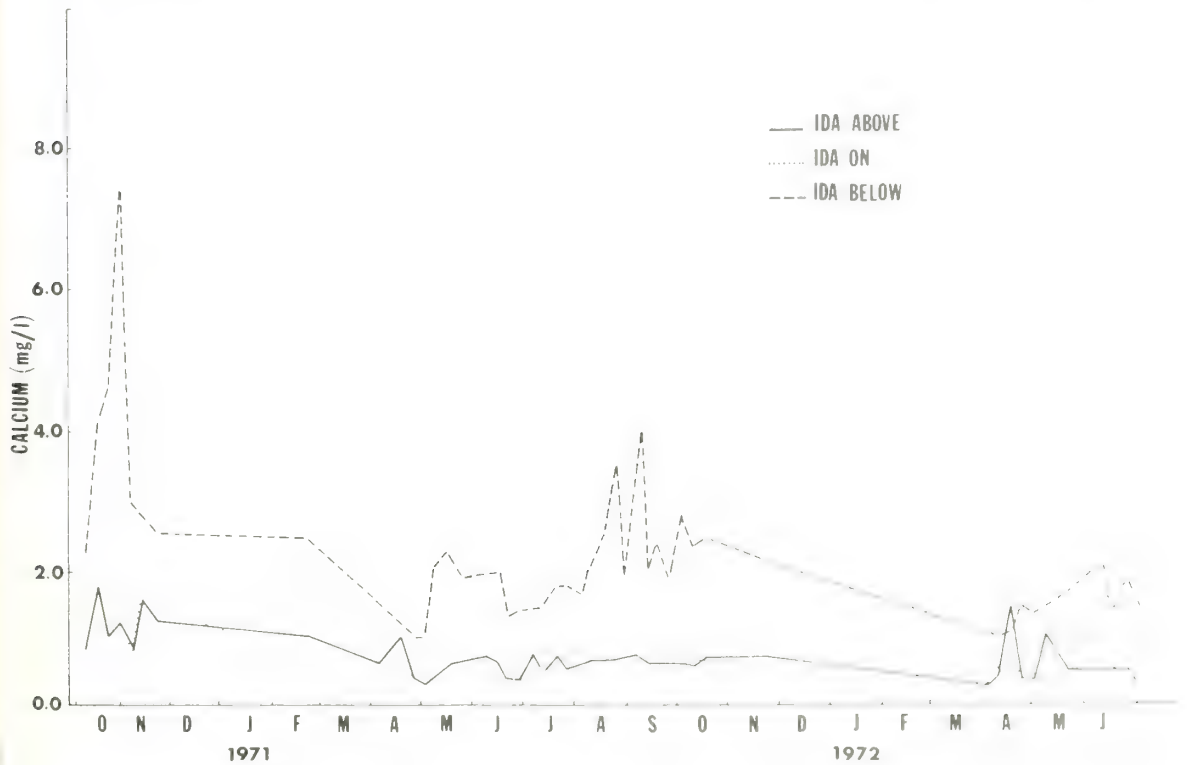

Figure 25.--Weekly average calcium values for the Ida Creek water sampling stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

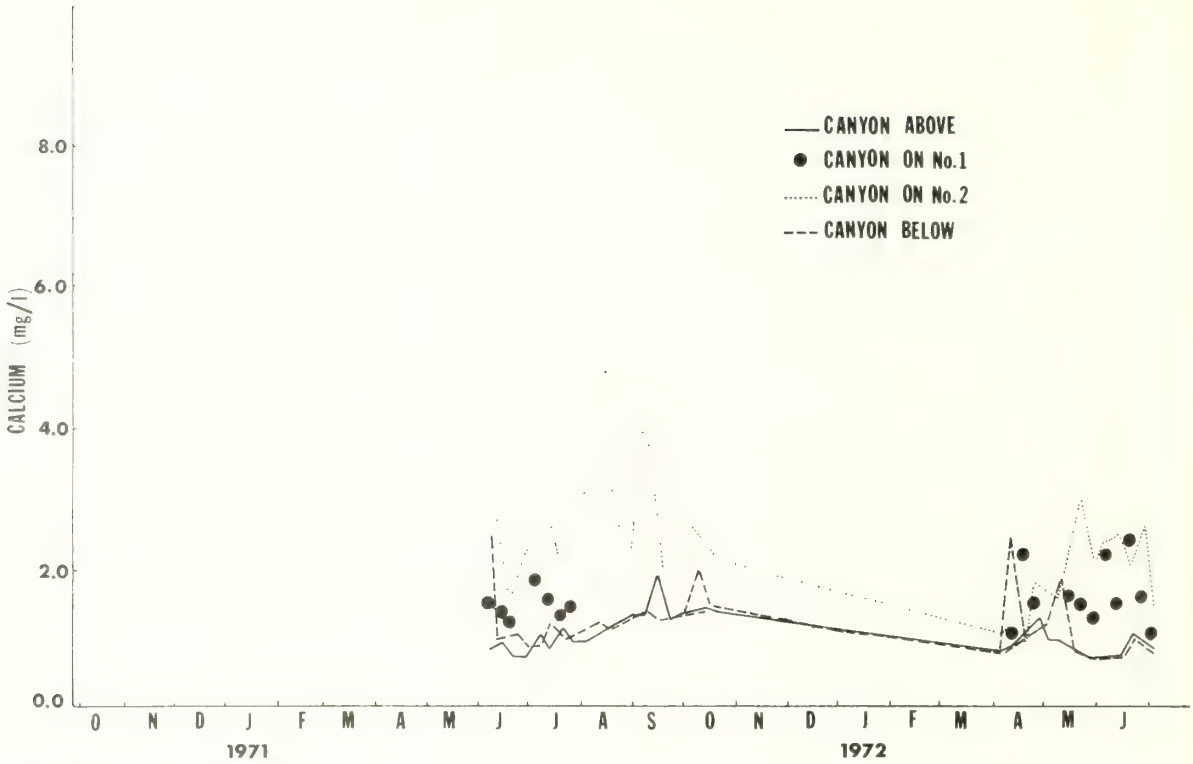

Figure 26.--Weekly average calcium values for the Canyon Creek stations. Control, on-site, and off-site stations are respectively designated "ABOVE," "ON," and "BELOW."

GENERAL DISCUSSION AND CONCLUSIONS

In the cedar-hemlock-grand fir ecosystem clearcutting of units of varying size (2.6 to 44 ha) and subsequent disposal of slash by prescribed burning resulted in on-site stream water quality changes. But off-site changes were of less intensity. Two of three clearcut units responded in this manner; a third unit gave different results. The physical and chemical components discussed represent the mean concentration per unit volume of discharge (or precipitation input) over a timespan of 21 months following land treatment.

Precipitation-Particulate Matter Input

Nitrate and potassium were the only nutrients in gross precipitation that equaled concentrations of these nutrients in the stream water at the ABOVE-site (control) stations. Incoming filterable solids (primarily atmospheric dust) exceeded by two to eight times the natural losses of filterable solids from undisturbed lands to stream water. All other precipitation nutrients were at lower concentrations than those in the stream water; only trace quantities of chloride could be detected in any precipitation sample.

On-Site Changes

Using the paired-station technique, comparisons of the physical and chemical parameters between most of the ABOVE-site (control) and ON-site (treated) stations indicated mean increases in pH, electrical conductivity, turbidity, filterable solids, bicarbonate, nitrate, sulfate, potassium, calcium, and magnesium. These ON-station increases also displayed large variances, ranging up to 116 times those calculated for the ABOVE-site stations.

With the exception of sodium, changes in cation concentrations between ABOVE and ON stations were lower than those reported by Tiedemann (1974) in his study of the effects of wildfire on water quality in central Washington. On the other hand, increases in cation concentration approximated those reported by Fredriksen (1971) in his evaluation of the effects of logging and slash burning on natural water quality in western Oregon.

Sulfate and bicarbonate were of particular interest because of the well-publicized studies by Likens and others (1970) conducted in the Northeast. They reported that the clearcutting of a small watershed, followed by treatment with herbicide, did not cause any increase in sulfate or bicarbonate concentrations in stream water. Our study at Priest River does not show this trend. We found that at all ON-site stations these anions increased in concentration after clearcutting and burning; the largest increase of any anion tested at Priest River was bicarbonate. These changes in bicarbonate concentration were of the same magnitude as reported by Fredriksen (1971).

Off-Site Changes

Comparisons between ABOVE-site (control) and BELOW-site (off-site) stations showed changes in fewer parameters, some barely significant. The parameters that did increase in concentration at most of the BELOW or downstream stations were bicarbonate, sulfate, calcium, magnesium, and electrical conductivity.

Benton and Canyon Creek ABOVE- and BELOW-site differences were generally less than ABOVE- and ON-site differences. At Ida Creek, increases were greater between ABOVE- and BELOW-sites. The local drainage pattern appears to play a dominant role in the reversal of nutrient concentration at the off-site stations. Although the steep slopes of the Benton clearcut-burn are dissected by first- and second-order channels, the surface runoff was ephemeral. Snowmelt runoff quickly collected in channels and transported a rich concentration of nutrients in solution. However, the overall volume of the side tributary was minimal compared with the volume in the main channel; hence, the process of dilution caused only slight increases in four nutrients.

A similar end point was reached at Canyon Creek, although the side tributary was perennial in constancy and produced a greater overall volume than at Benton Creek. We observed a significant increase in nutrient concentration after water emerged from the spring (ON #1 station) and flowed through a moderately incised channel to ON #2 station. Again, highly enriched and low in overall volume, the side tributary caused little impact on the main channel because of dilution. Small increases were detected in three chemical components.

Ida Creek has a markedly different drainage pattern. The logged area, located at the headwaters, lies downslope from a large spring and upslope from the point in Ida Creek of year-around surface flow. Water from the spring flows through the ABOVE-site station and onto the clearcut-burn to the ON-site station where it submerges, moves as subsurface flow, and reemerges to provide the bulk of the Ida Creek flow.

Uptake of nutrients increased progressively as the water moved on the surface to the ON-site station and, especially, as it percolated through the lower half of the clearcut-burn. Apparently, large quantities of leachate moved laterally from the nutrient-enriched surface layers. Unique to the Ida Creek site were the higher mean readings for certain nutrients at the off-site station because of the absence of a large volume of stream water. Thus a process of concentration rather than dilution prevailed.

Seasonal Trends and Runoff

Bicarbonate, sulfate, magnesium, and electrical conductivity increased between the ABOVE- and BELOW-site stations and displayed dependence upon seasonal runoff. Concentrations were lowest during high spring flows and highest during low flows. Tiedemann (1974) attributed similar trends to the dilution effect since lowest

concentrations coincided with peak snowmelt runoff. Of the constant off-site parameters remaining (turbidity, suspended solids, pH, chloride, nitrate, sodium, and potassium), sodium was the only ion that displayed dependence upon seasonal runoff patterns.

Stream Ecology

The impacts of dissolved nutrients on the downstream ecology are generally unknown. However, such aquatic organisms as algae, which may contribute to eutrophication, thrive and grow if essential nutrients are available. Greeson (1969) lists the minimum concentrations of many essential nutrients for the growth and reproduction of algae. Minimum requirements for most of these nutrients are at trace levels. Many, if not all, of these ions are constituents of soils and could be added to natural waters through leaching. Without exception, nutrients found at the ABOVE-site stations in Benton Creek, Canyon Creek, and Ida Creek exceeded the minimal requirements of algae (table 5).

From the standpoint of hazard to humans, increased concentrations did not exceed U.S. Public Health Service (1962) standards for drinking water.

Table 5.--*Elements essential for the growth and reproduction of algae* [1/]

Element	Symbol	Minimum requirements
Calcium	Ca	Trace quantities
Chlorine	Cl	Trace quantities
Magnesium	Mg	Trace quantities
Nitrogen	N	Trace - 5.3 mg/ℓ
Phosphorus	P	0.002 - 0.09 mg/ℓ
Potassium	K	Trace quantities
Silicon	Si	0.5 - 0.8 mg/ℓ
Sodium	Na	Trace quantities
Sulphur	S	5.0 mg/ℓ

1/ Condensed from Greeson's (1969) table 1, page 26, except calcium and sodium.
2/ Personal communication, Dr. A. J. Lingg, University of Idaho.

Buffer Strips

The utility of buffer strips as filters for suspended sediment is suggested by the significant differences in filterable solids between ABOVE- and ON-site stations and the nonsignificant increases between ABOVE- and BELOW-site stations. We also observed the effectiveness of the forest floor as a microbarrier to sediment-laden water. We cannot quantify the utility of strips as sediment traps. However, our data, along with those of others, indicate that utility in stream-temperature moderation and reduction in bank scouring suggest that buffer strips should continue to be used as a management tool.

Whether or not buffer strips will filter nutrients in solution is problematical. Perhaps, the major benefit of a buffer strip is that it will act as a physical barrier to direct contact with a nutrient source. In view of the high concentration of nutrients measured at the ON-site station we can speculate that unlogged or unburned strips adjacent to water courses *within* the clearcut unit would not have provided a ready source of nutrients for leaching. Until more knowledge is gained, the prudent manager should be very cautious about removing trees in the proximity of springs, seeps, and water courses. If he wishes to eliminate logging slash, he should do so by means other than burning.

LITERATURE CITED

American Public Health Association, Inc.
1971. Standard methods for examination of water and wastewater including bottom sediments and sludges. 13th ed. 874 p. Am. Public Health Assoc., Inc.

Brown, E., M. W. Skougstad, and M. J. Fishman.
1970. Methods for collection and analysis of water samples for dissolved minerals and gases. U.S. Geol. Surv., Book 5, Ch. A1, 160 p.

Brown, G. W., A. R. Gabler, and R. B. Marston.
1973. Nutrient losses after clear-cut logging and slash burning in the Oregon coast range. Water Resour. Res. 9(5):1450-1453.

Cole, D. W., and S. P. Gessel.
1963. Movement of elements through a forest soil as influenced by tree removal and fertilizer additives. *In* Forest-soil relationships in North America. p. 95-104. Chester T. Youngber, ed. Oreg. State Univ. Press, Corvallis.

Cole, D. W., and S. P. Gessel.
1968. Cedar River research, a program for studying the pathways, rates, and processes of elemental cycling in a forest ecosystem. Inst. For. Prod., Univ. Wash., No. 4, 54 p.

DeByle, N. V., and P. E. Packer.
1972. Plant nutrient and soil losses in overland flow from burned forest clearcuts. *In* Natl. Symp. Watersheds in Transition, p. 296-307. Colo. State Univ.

Fredriksen, R. L.
1971. Comparative chemical water quality - natural and disturbed streams following logging and slash burning. *In* Forest and land uses and stream environment, p. 125-137. Oreg. State Univ., Corvallis.

Greeson, P. E.
1969. Lake eutrophication--a natural process. Water Resour. Bull. 5(4):16-30.

Likens, G. E., F. H. Bormann, N. M. Johnson, and R. S. Pierce.
1967. The calcium, magnesium, potassium, and sodium budgets for a small forested ecosystem. Ecology 48(5):772-785.

Likens, G. E., F. H. Bormann, N. M. Johnson, and others.
1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. Ecol. Monogr. 40(1):23-47.

Marston, R. B.
1967. Pollutional concentrations and loads of some natural constituents and their relation to streamflow, before and after road building and tree harvesting in some small Alsea River watersheds in Western Oregon. U.S. Dep. Inter., FWPCE, Pac. Northwest Water Lab. Prog. Rep., 18 p.

Packer, P. E.
1965. Forest treatment effects on water quality. *In* International Symposium on Forest Hydrology, p. 687-699. Penn. State Univ.

Rothacher, J., C. T. Dryness, and R. L. Fredriksen.
1967. Hydrologic and related characteristics of three small watersheds in the Oregon Cascades. USDA For. Serv., Pac. Northwest For. and Range Exp. Stn., 54 p. Portland, Oreg.

Skau, C. M., R. O. Meeuwig, and J. H. Humphrey.
1971. Watershed research on the eastside Sierra Nevada. Presented before IUFRO, 15th Congr., Gainesville, Fla., 4 p.

Streebin, L. E., J. M. Robertson, C. Bradshaw, and others.
1970. Rock Creek water quality study. 105 p. Sch. Civil Eng. and Environ. Sci., Univ. Okla.

Tarrant, R. F.
1971. Statement of, presented before hearing of the Subcommittee on Public Lands, Committee on Interior and Insular Affairs, U.S. Senate. On the Management of Public Lands. U.S. Gov. Print. Off., Washington, D.C.

Tiedemann, A. R.
1974. Stream chemistry following a forest fire and urea fertilization in North Central Washington. USDA For. Serv. Res. Pap. PNW-203, 20 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

U.S. Public Health Service.
1962. Drinking water standards. 956 p. U.S. Dep. Health, Educ., and Welfare, Public Health Serv., Washington, D.C.

U.S. Senate.
1971. Hearing of the Subcommittee on Public Lands, Committee on Interior and Insular Affairs. On the Management of Public Lands. U.S. Gov. Print. Off., Washington, D.C.

Weisel, G. F., and R. L. Newell.
1970. Quality and seasonal fluctuation of headwater streams in western Montana. Mont. For. and Conserv. Exp. Stn. Bull. 38, 16 p.

U.S. GOVERNMENT PRINTING OFFICE: 1974 — 677-097 / 57 REGION NO. 8

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1975. Clearcutting and burning slash alter quality of stream water in northern Idaho. USDA For. Serv. Res. Pap. INT-168, 34 p., illus. (Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.)

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OXFORD: 116.0, 116.25, 221.1, 116.28, 232.213.
KEYWORDS: watershed management, fire (hydrology), clearcutting systems, logging (hydrology), regeneration (fire use).

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Provo, Utah (in cooperation with Brigham

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FROM

CHARACTERISTICS AND HYBRIDIZATION OF IMPORTANT INTERMOUNTAIN SHRUBS. I. ROSE FAMILY

A. Clyde Blauer, A. Perry Plummer, E. Durant McArthur, Richard Stevens, and Bruce C. Giunta

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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401
Roger R. Bay, Director

AUTHORS

A. CLYDE BLAUER is an assistant professor of Life Sciences, Division of Natural Sciences, Snow College, Ephraim, Utah. He received his B.S. (1964) and M.S. (1965) degrees in botany from Brigham Young University. He has received additional postgraduate training at Cornell University in plant pathology and plant breeding (1965-1966) and the University of Alabama in algology (1973). Since 1967, he has done botanical work each summer for the Intermountain Station in Ephraim.

A. PERRY PLUMMER is the project leader and range scientist for the Intermountain Station at Ephraim. He has worked in range research for the Station since 1936. He received his B.S. degree (1935) and his M.S. degree (1939) in botany from the University of Utah. His research has been principally concerned with restoration of western ranges.

E. DURANT McARTHUR is a research geneticist for the Intermountain Station at Provo. His degrees are from the University of Utah: B.S. in genetics and cytology (1965), M.S. in molecular and genetic biology (1967), and Ph.D. in biology (1970). He was a Postdoctoral Research Fellow of agricultural botany at the University of Leeds, United Kingdom, in 1970-1971. He joined the Station in 1972.

RICHARD STEVENS is a wildlife resources biologist for the Utah Division of Wildlife Resources stationed in Ephraim. He received his B.S. degree in range management (1965) from Brigham Young University and his M.S. degree in range management (1968) from The University of Arizona. From 1968 to 1969 he was a range conservationist with the USDA Forest Service. He has been in his present position since 1969.

BRUCE C. GIUNTA is a wildlife resources biologist for the Utah Division of Wildlife Resources. He has been stationed at Ephraim since 1971. He began work for the Division in 1969 as the wildlife management area supervisor for the Hardware Game Management Unit. He received both his B.S. in wildlife management (1963) and his M.S. in wildlife biology (1968) from Colorado State University.

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ABSTRACT

Rosaceous shrubs are an important component of the vast shrublands of the Intermountain area. They provide forage and cover for animals, esthetic beauty for man, and are of value as soil stabilizers. The general vegetative, floral, reproductive, hybridization, distribution and habitat, and use characteristics are described and reviewed for Amelanchier alnifolia, A. utahensis, Cercocarpus intricatus, C. ledifolius, C. montanus, Cowania mexicana var. stansburiana, Fallugia paradoxa, Peraphyllum ramosissimum, Purshia glandulosa, P. tridentata, and Rosa woodsii. Artificial hybridization studies demonstrate the fundamental genetic compatibility in the Purshia-Cowania-Fallugia group. A taxonomic key covering each taxon discussed is provided.

INTRODUCTION

Shrubs dominate much of the vegetation in the Western United States and form characteristic types from the lowest deserts to the tops of the mountains (Plummer 1974). There are approximately 325 million hectares (700 million acres) of shrubland over this broad area. In Utah, shrubby plants dominate or characterize approximately 75 percent of the vegetation (McArthur and others 1974). Most shrubs are palatable and are important components of the forage consumed by big game and livestock on the western ranges. In addition, some shrubs are useful for stabilizing and beautifying roadcuts, mine spoils, and other raw, exposed soils, as well as for landscaping residential, commercial, and recreational areas.

Some of the most important browse and ornamental shrubs belong to the rose (Rosaceae) family. Ecotypes within species exhibit immense variation. Some rosaceous shrubs in association with micro-organisms can fix nitrogen (Webster and others 1967; Hoeppel and Wollum 1971; Krebill and Muir 1974). This is a particularly valuable trait in nitrogen-deficient soils common on western wildlands. Natural hybridization of species of the same genus and even between genera is fairly common. Therefore, we believe by careful selection and artificial hybridization these shrubs can be improved for a variety of purposes, but particularly for increased browse on big game ranges and for cover on disturbed areas such as roadcuts and mine spoils.

The purpose of this paper is to document what is presently known about some important browse shrubs of the rose family in the Intermountain area with regard to their vegetative and flowering characteristics, hybridization, distribution, and use. Most of the observational information and experimental data was gathered from the Intermountain area (Holmgren and Reveal 1966), especially from Utah. Holmgren and Reveal's Intermountain area includes all of Utah, that portion of Arizona north of the Grand Canyon, most of Nevada, parts of California that lie within the Great Basin, the sagebrush areas of southeastern Oregon, southern Idaho to the high mountainous areas to the north, and the red desert area of southwestern Wyoming. However, comment and reference to species distribution and attributes outside this area are made when pertinent. We believe this will be helpful in formulating the basis for genetic improvement of these shrubs for specific needs.

Each species, its hybridization, distribution, and use are described in detail. Each genus and its included species are arranged in alphabetical order. A key for the included genera and species is given (appendix).

METHODS

A survey of literature, particularly of pertinent keys and monographs, was conducted before hybridization experiments began. In addition, some observations of flo and vegetative characteristics were made during 1967 and later growing seasons. Colle tions were made of shrubs in various stages of development for illustrative purposes. Artificial hybridization was tried between *Cowania mexicana* var. *stansburiana*, *Purshia tridentata*, *Fallugia paradoxa*, and the *Cowania-Purshia* hybrid by treating emasculated flowers of each with pollen from the others (fig. 1). Flowers which were to receive pollen or to serve as controls were covered with white paper bags before anthesis (fig. 1). These artificial crosses were made to determine if there are any major diff culties in interspecific hybridization within and between these closely related genera

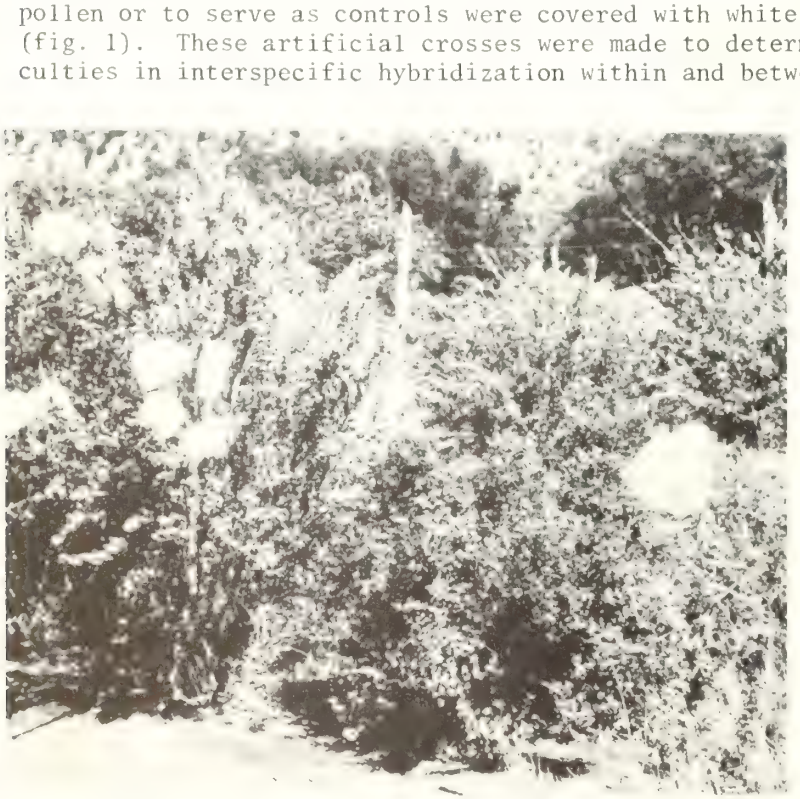

Figure 1.--Cliffrose (Cowania mexicana *var.* stansburiana) *with flowers emasculated, bagged, and pollinated with antelope bitterbrus* (Purshia tridentata) *and Apache plume* (Fallugia paradoxa) *pollen.*

Figure 2.--Germinated seeds of antelope bitterbrush.

Viability of the seed produced from the controlled pollinations was determined by placing evenly distributed seed on moistened newspapers or paper towels, which were then folded in half. The folded papers were covered by plastic sheets and placed in refrigerators at temperatures maintained between 1° and 4° C for 6 months. This temperature treatment is adequate to break seed dormancy of most rosaceous shrubs (fig. 2).

Seedlings from sprouted seeds were transplanted to pint or quart milk cartons and placed in greenhouses to develop (fig. 3). The milk cartons had holes punched in their bases to allow drainage. Plants were watered when the soil was dry.

Seedlings of the various crosses that had been obtained since 1968 were transplanted late in May 1971, to range adaptation plots just south of Manti, Utah.

Figure 3.--An antelope bitterbrush X Stansbury cliffrose hybrid seedling produced by artificial hybridization.

SPECIES CHARACTERISTICS

Amelanchier alnifolia (Saskatoon serviceberry)

Saskatoon serviceberry is an erect deciduous shrub 1 to 4.5 m tall (fig. 4), with gray bark on older stems and smooth, reddish-brown bark on younger stems.

The leaves are simple, alternate, and usually borne on short, lateral branchlets. They are up to 5 cm long and 2.5 cm wide, with serrate margins above the middle, and are usually glabrous at maturity, although this quality varies somewhat between ecotyp

The showy, white, epigynous flowers are borne in short, erect racemes. They contain persistent sepals, five deciduous, oblanceolate petals about 12 mm long, numer ous stamens, and a single pistil usually with five styles.

Figure 4.--Saskatoon servi berry growing near Kanas Utah. Picture taken in early October 1967 afte leaves had dropped and fruits had dried. Note dried fruits on uppermo branches. Scale is in feet.

Figure 5.--Saskatoon serviceberry branch showing leaves and [illegible] fruit.

The edible glabrous fruit is a bluish or purplish globe-shaped pome 5 to 9 mm in diameter (fig. 5). It is five-celled. Each cell contains one or two seeds. Saskatoon serviceberry averages 45,395 cleaned seeds per pound (100/g) (Plummer and others 1968).

Considerable variation is present in the shape, size, amount of pubescence, and serrations on leaf margins (fig. 6). Seed size is also highly variable.

Flowers bloom during May and June and fruits ripen during July and August. Numerous blossoms occur almost every year, but because of frost and juniper rust (*Gymnosporangium*) infestations, good seed crops may only be produced every 3 to 5 years.

Figure 6.--Variation in Saskatoon serviceberry leaves. The leaves are from three different bushes representing three accessions.

Hybridization: There are wide differences in ecotypes of Saskatoon serviceberry. Some have proven much more resistant to juniper rust than others. No doubt resistance to disease and other desired characteristics can be improved through intraspecific and interspecific hybridization. *Amelanchier* is noted for its intergradation between species (Jones 1946; Hitchcock and others 1961; Cruise 1964).

Observations to date indicate that stigmas mature before anthers. Thus, artificial hybridization by mass pollination should be possible without having to emasculate flowers, particularly if they prove to be self-incompatible.

Distribution and Habitat: Saskatoon serviceberry grows under a variety of environmental conditions. It is a fairly important shrub throughout the juniper-pinyon type and is sometimes common in big sagebrush lowlands. This species is most prolific in relatively moist, sloping habitats in openings within or just below the ponderosa pine (*Pinus ponderosa*) type. Its range extends from California eastward throughout the Rocky Mountains to Nebraska and Michigan and as far north as Alaska.

Use: Serviceberry is a valuable browse plant due to its fair-to-high palatability and ready availability to livestock and big game. It is browsed by cattle after midsummer when the more palatable grasses and forbs have been grazed or have dried up. Big game show varying preference for this shrub. They use it chiefly in the fall and winter. The fleshy fruits (pomes) are sought by a wide variety of birds and mammals. Some people harvest them for jams and jellies.

Amelanchier utahensis (Utah serviceberry)

Utah serviceberry is a shrub 0.5 to 5 m tall (fig. 7), with numerous branched, pubescent, ash-gray twigs.

Figure 7.--A Utah serviceberry bush near Canaan Mountain, Washington County, Utah.

The leaves are 1 to 3 cm long, somewhat leathery at maturity, and usually permanently pubescent, with soft, crisp, often yellowish hairs, particularly on the lower surface.

Flowers consist of 5 sepals, which are reflexed and persistent, five white petals, 5 to 10 mm long, numerous stamens, and usually two or three styles. The ovary is inferior, or nearly so, with false partitions forming twice as many cells as there are styles. The flowers bloom during May and June and fruits mature in the fall.

The pomaceous fruit is finely pubescent and green when young, changing at maturity to a yellow or golden color, not juicy, and 6 to 7 mm broad. Fruits often dry and harden on the bushes and may persist for as long as 2 years or until removed by small mammals or birds. Utah serviceberry averages 25,800 cleaned seeds per pound (57/g) (Plummer and others 1968).

Hybridization: Davis (1952) and some other authors relegate this species to a subspecies of *Amelanchier alnifolia*. We believe with Jones (1946) that specific status is warranted by its different fruiting and growth habits. Putative hybrids between these two species have been noted, particularly where they occur together. Improvement of various desired characteristics by selection and artificial hybridization between Utah and Saskatoon serviceberry should be possible. Cruise (1964) showed that gene exchange is common in *Amelanchier* species in eastern North America.

Distribution and Habitat: Utah serviceberry occurs in Colorado, Utah, Nevada, California, Arizona, and New Mexico. It grows in foothills from 610 to 2,590 m (2,000 to 7,000 feet) on dry, rocky slopes (fig. 7), and is associated with a wide range of shrubs and trees, including sagebrush (*Artemisia* spp.) pinyon pines (*Pinus edulis* and *P. monophylla*), ponderosa pine, and aspen (*Populus tremuloides*). This species is most common in southwestern Utah and southeastern Nevada. It is generally found on drier sites than Saskatoon serviceberry. Where they occur together, Saskatoon serviceberry is found in the more mesic swales and Utah serviceberry on the outer ridges.

Use: Utah serviceberry provides good forage for cattle and good to excellent browse for sheep and goats, principally in early spring because it leafs out and blooms earlier than most associated shrubs. Deer browse the shrub throughout the year, but are most dependent on it during winter. Persistence of dried fruits on the bushes aids the survival of birds and small mammals through critical periods in the winter and spring.

Cercocarpus — Common Floral Characteristics

This genus has small, inconspicuous perigynous flowers which occur solitarily or in axillary or terminal groups. The flowers have five deciduous sepals attached to the rim of the hypanthium, numerous stamens inserted in two to three rows on the hypanthium, and one pistil. Petals are lacking. Although flowers are quite similar in all species of mahogany, curlleaf (*C. ledifolius*) tends to have the largest flowers, littleleaf (*C. intricatus*) the next largest, and true mountain mahogany (*C. montanus*) the smallest. The achene terminates in elongated, hairy, persistent, variously curved or twisted styles or plumes (fig. 8 and 16).

Figure 8.--Mountain mahogany branch comparison. Left to right: Cercocarpus intricatus, C. ledifolius, C. ledifolius X C. montanus *hybrid*, C. montanus

Cercocarpus intricatus (Littleleaf mountain mahogany)

Littleleaf mountain mahogany is a small, intricately branched shrub to 2.5 m tall (fig. 9), with narrowly linear and strongly revolute leaves (fig. 8), usually less than 12 mm long. *Cercocarpus intricatus* averages 50,910 cleaned seeds per pound (112/g) (Plummer and others 1968).

Hybridization: Cercocarpus intricatus hybridizes with both *C. ledifolius* and *C. montanus*. Stutz (1974) suggests that *C. intricatus* is a dry, harsh site segregant of *C. ledifolius*.

Figure 9.--Littleleaf mountain mahogany heavily hedged on foothills east of Ephraim, Sanpete County, Utah.

associated with
Artemisia nova

Littleleaf mountain
are exposed to high temperatures and drought
entirely to Utah, Nevada, and northern Arizona.
form in Washington and Oregon called
others 1961).

Like all mountain mahogany
It is an excellent winter feed for deer.

Cercocarpus ledifolius (Curlleaf mountain mahogany)

Curlleaf mountain mahogany is an erect shrub or sometimes a small tree to 7 m. tall (fig. 11).

Figure 11.--Curlleaf mountain mahogany near Wasatch Pass, Sevier County, Utah.

Figure 12.--Mountain mahogany leaf comparison. Upper left, Cercocarpus intricatus; *lower left,* C. ledifolius, *center, hybrids; right,* C. montanus.

The leathery, evergreen leaves are elliptic to lanceolate, 12 to 25 mm long, and less than 12 mm wide. They are somewhat resinous and glabrous above, white hairy beneath, with entire revolute margins, and a prominent midrib.

The plumose style on the fruit is 50 to 75 mm long. The flowering period extends from May to June, and fruit ripens from May to August. Curlleaf mountain mahogany averages 51,865 cleaned seeds per pound (114/g) (Plummer and others 1968).

Hybridization: Natural hybrids (fig. 12 and 13) between true mountain mahogany (*C. montanus*) and littleleaf mountain mahogany have been observed in most places where their respective ranges overlap.

Figure 13.--Natural hybrid between curlleaf mountain mahogany and true mountain mahogany.

Stutz (1971) suggested that [illegible] and [illegible]. He believes [illegible] may have evolved to fit its present mesic habitat by gradual broadening and enlargement of its leaves and development of its deciduous habit. He also theorizes that *Cercocarpus intricatus* evolved to fit a more xeric habitat by developing smaller, narrower leaves, which it retains even when growing in more moist riparian conditions.

The chromosome number of curlleaf mountain mahogany is $2n = 16$ (Pyrah 1964).

[illegible]: Curlleaf mountain mahogany grows between elevations of 1,830 and 2,740 m (6,000 and 9,000 feet) in Utah on dry, rocky ridges usually on southern or western slopes. Occasionally, it can be found in canyon bottoms. It grows on slopes and among cliffs (fig. 14). Its range extends from Montana to Washington, south to Colorado, northern Arizona, and California.

Use: Curlleaf mountain mahogany is excellent winter game browse. In contrast to true mountain mahogany, it is not fire tolerant, which may explain its absence on many areas where it has occurred and would otherwise grow. This is likely the reason it is often confined to rocky and severe sites that are not susceptible to burning because of lack of fuel. Fire tolerance could be bred into it from *C. montanus*. Unfortunately, because of the arborescent habit of this species, the bulk of the foliage in mature stands is out of the reach of grazing animals (fig. 11); stands are often highlined as high as the animals can reach. Thompson (1970) found that available browse in *C. ledifolius* in the Manti-LaSal National Forest in central Utah could be increased considerably if tops were pruned from April 20 to May 10 and from September 10 to 30. Topping during other periods resulted in complete mortality. He reported that top-pruned trees often produced to 200 percent more growth than unpruned trees. He therefore suggested that this method could be used as a means of increasing available browse on selected sites of big game winter ranges. Wood of curlleaf mountain mahogany has a high density and burns slowly. It is prized as a barbecue fuel.

[illegible] mountain mahogany growing on and below granite [illegible], [illegible] Mountains, Beaver County, Utah.

Cercocarpus ledifolius X *C. montanus* hybrid

These hybrids are more erect and somewhat taller than the true mountain mahogany growing in the same area. Their stature is more akin to that of curlleaf mountain mahogany (fig. 11 and 13).

The leaves of the hybrid are highly variable. In some instances, they resemble curlleaf mountain mahogany and in other true mountain mahogany. While the persistence of leaves on hybrid shrubs is more characteristic of curlleaf mountain mahogany than true mountain mahogany, there is considerable variation of leaf persistence between individual native hybrid plants. The hybrid is usually 2 to 4 weeks later in flower development than true mountain mahogany. In this respect it is more like curlleaf mountain mahogany.

Hybridization: These plants are products of hybridization. They hybridize with both parental species to form first and later generation backcrosses.

Distribution and habitat: These hybrids occur in many places where the two parent species are or have been contiguous. This has been particularly noted in Utah. Like *C. montanus*, the hybrid apparently has some fire tolerance since it occurs on fire scar where *C. ledifolius* is no longer present.

Use: The *C. ledifolius* X *C. montanus* hybrid is an excellent browse. However, because of its large stature, substantial portions of its twigs and foliage are unavailab to browsing animals.

Cercocarpus montanus (True mountain mahogany)

True mountain mahogany is a shrub to 4 m in height or rarely a small tree to 6 m i height (fig. 15). Leaves are deciduous, short-petioled, to 5 cm long and 2.5 cm wide, and flat, with dentate margins (fig. 8 and 12). The plumose style (fig. 16) on the fruit measures to 10 cm in length. Depending on elevation, the flowering period varies from mid-May to late June, and fruit ripens from late July to mid-September. This species is highly fire tolerant and resprouts vigorously on burns.

Figure 15.--True mountain mahogany.

mahogany showing a typical (near center).

The following effect of elevation on flower and fruit [illegible] by this species. On June 18, 1967, at an elevation of 2,380 m (7,800 feet), true mountain mahogany was in late flower. Only 2 days later, at an elevation of 1,830 m (6,000 feet), it was in late fruit. True mountain mahogany averages 59,030 cleaned seeds per pound (130/g) (Plummer and others 1968).

There is a wide variation in ecotypes both geographically and by elevation. Leaf size and shape are variable (fig. 12). A number of small-leafed true mountain mahogany shrubs occur west of Richfield, Utah, on the lower foothills of the Pahvant Range. These appear to be a distinctly different ecotype than those growing elsewhere.

The chromosome number of true mountain mahogany is 2n [illegible]

Hybridization: Our observations indicate that the stigmas of true mountain mahogany mature before the stamens. Consequently, we believe artificial hybridization by mass pollination would be possible when the flowers first open.

Natural hybridization between the deciduous *C. montanus* and the everg[illegible] *C. ledifolius* and *C. intricatus* occurs at many places in Utah where their ranges over[illegible] (fig. 13). Plummer and others (1957) reported that the more vigorous semi[illegible] hybrids of *C. montanus* X *C. ledifolius* are relatively common in Utah, particularly al[illegible] the west slopes of the Wasatch Plateau and the Wasatch Mountains. Pyrah [illegible] that hybrids of *C. ledifolius* X *C. intricatus* are common because their flo[illegible] overlapped. He found that hybrids of *C. montanus* X *C. ledifolius* are less common because of a 2-week flowering period difference between the parental speci[illegible] tion between *C. montanus* and *C. intricatus* was reported to be rare (Pyrah 1964). Development of strains useful for a variety of purposes, particularly range restoration, should be possible by selection and artificial hybridization. Mountain ma[illegible] ies and hybrids can often be distinguished by leaf characteristics (fig. 12).

Figure 17.--True mountain mahogany growing on herb-depleted south-facing slope in Miller Canyon southeast of Nephi, Juab County, Utah.

Distribution and Habitat: True mountain mahogany occurs from 1,220 to 3,040 m (4,000 to 10,000 feet) over a wide range of habitats from the Rocky Mountains westward with eastward extensions into South Dakota and Montana. It often grows in coarse, shallow soil on south- or west-facing slopes and ridges (fig. 17), but is also common in the more moist, fertile, deeper soils of canyon bottoms and on north slopes at lower elevations (fig. 18).

This species is frequently associated with gambel oak (*Quercus gambelii*), Utah juniper (*Juniperus osteosperma*), pinyon pines, ponderosa pine, serviceberry, bitterbrus *(Purshia tridentata)*, manzanita (*Arctostaphylos* spp.), buckbrush (*Ceanothus* spp.), species of rabbitbrush (*Chrysothamnus*), and species of sagebrush. *Cercocarpus montanus* is often the dominant species of the association and frequently occurs in nearly pure stands.

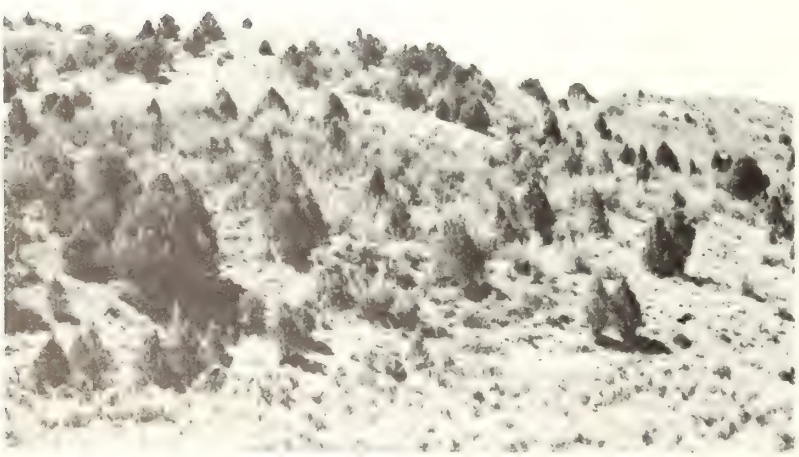

Figure 18.--True mountain mahogany growing with Utah juniper on a north-facing slope in Salina Canyon, Sevier County, Utah.

A similar but taller species, birchleaf mountain mahogany [illegible], occurs quite commonly in the Sierra Nevada Mountains, retains its leaves in the winter. The extent to which it hybridizes with true mountain mahogany is not known, but we believe they would cross readily.

Use: True mountain mahogany is grazed by all classes of grazing animals in the summer and winter and is one of the more valuable winter browse plants of deer.

Cowania mexicana var. *stansburiana* (Stansbury cliffrose or cliffrose)

Stansbury cliffrose is a much-branched evergreen, shrubby or arborescent plant, 1 to 6 m tall (fig. 19), and is often resinous and strong smelling. The stems are erect, rather stiff, and have gray, shreddy bark.

Leaves are clustered along the branchlets and are 12 to 25 mm long, with revolute margins and a five- to seven-toothed apex. They are light-to-dark green, glandular, dotted above, and more or less white tomentose beneath.

The fragrant, showy flowers are bisexual or rarely staminate (McMinn 1951). They are solitary, on short branchlets, and approximately 20 mm broad. Flowers are perigynous with five persistent sepals and five cream or sulphur-yellow petals. The numerous stamens occur in two series, enveloping 5 to 12 hairy pistils (fig. 20). The fruits are achenes, each about 3 mm long and tailed by a plumose style 25 to 50 mm long (fig. 21, 26, 35).

Flowers bloom from May to June and fruits ripen from July to August. There are often two blooming periods, one in June and another in August. The second blooming is usually dependent on summer storms. The best seed results from the first blooming period, although some seed may be produced in September and October from the later blooms.

Figure 19.--Large Stansbury cliffrose growing north of Nona, Juab County, Utah.

Figure 20.--Stansbury cliffrose flower: left, *in full bloom;* right, *developing achenes.*

Figure 21.--Stansbury cliffrose flower showing developing achene. Note the long feathery styles.

Figure 22.--Achenes developing on a natural hybrid between antelope bitterbrush and cliffrose.

Flowers in all stages of bloom were studied at different locations to determine which matured first, stigmas or stamens. No definite conclusion was reached. Both organs may mature about the same time. Soon after the flower opens, the stigma appears to be receptive and some of the outer stamens are starting to dehisce.

Seeds are tightly held in the achene and are separated only by intense rubbing, whereas, seeds of cliffrose relatives, antelope and desert bitterbrush (*Purshia glandulosa*) readily separate from their achenes. Stansbury cliffrose averages 64,615 cleaned seeds per pound (142/g) (Plummer and others 1968).

Cliffrose has a chromosome number of $n = 9$ (Stebbins 1959).

Hybridization: Natural hybrids of Stansbury cliffrose crossed with antelope bitterbrush (fig. 22) or desert bitterbrush are fairly common where the ranges of these species overlap.

A small population of putative Stansbury cliffrose-Apache plume hybrids occurs along Ranger Pass about 12 miles west of the Big Springs Ranger Station, Kaibab National Forest, Arizona (fig. 23). Both parents also occur in this vicinity. This population contains the only known natural hybrids between these two species. On July 25, 1968, 72 seeds were collected from these hybrids and 16 (22.2 percent) germinated. Only two of these seedlings grew into young plants.

Artificial hybridization performed by treating emasculated flowers of Stansbury cliffrose (fig 24) with pollen from Apache plume, antelope bitterbrush, and the cliffrose-bitterbrush hybrid has produced viable seed and seedlings (table 1).

Viable seeds have also been obtained by artificially pollinating emasculated flowers of bitterbrush, the bitterbrush-cliffrose hybrid, and pistillate flowers of Apache plume with Stansbury cliffrose pollen (table 1).

Figure 23.--A putative natural hybrid between Stansbury cliffrose and Apache plume in the Kaibab National Forest, Coconino County, Arizona.

Stansbury cliffrose is essentially self-incompatible. This characteristic was determined by bagging branches of cliffrose which had flowers still in bud and also branches on which all buds were emasculated. No pollen was added to the sacks. The emasculated flowers produced no viable seed. The nonemasculated flowers produced only 10 viable seeds (1968-71). Three of these were produced by a branch on which the paper sack had been punctured, possibly allowing extraneous pollen to enter. The other seeds, however, were produced on branches covered by intact sacks. These nonemasculated control flowers bore 500 seeds, of which 10 germinated for a percentage of 2.0, compared to 3.3 percent for Stansbury cliffrose crossed with Apache plume and 53.9 percent for Stansbury cliffrose crossed with antelope bitterbrush (table 1).

Figure 24.--A Stansbury cliffrose flowerbud in proper stage of development for emasculation.

Table 1.--*Seed and seedlings obtained from artificial hybridization between Stansbury cliffrose (Comes), antelope bitterbrush (Putr), cliffrose-bitterbrush hybrid (Hybrid), and Apache plume (Fapa)*[1]

Maternal (seed) plant	Paternal (pollen) plant	No. of seeds collected 1967-1971	No. of seeds germinated	Percent germination 1967-1971	Percent germination Low	Percent germination High	No. of seedlings alive 8/28/72
Comes	Fapa	[2]1,418	47	3.3	0.0	4.2	7
Comes	Putr	[3]1,544	832	53.9	.0	63.5	97
Comes	Hybrid	[4]592	396	66.9	29.4	80.0	28
Putr	Fapa	[5]19	19	100.0	-	-	7
Putr	Comes	606	491	81.0	71.7	92.5	108
Putr	Hybrid	185	171	92.4	91.4	94.1	31
Fapa	Comes	[7]3,647	[6]19	.52	.0	14.3	0
Fapa	Putr	[7]1,899	10	.53	--	-	0
Fapa	Hybrid	[7]1,735+	0	.0	--	--	0
Hybrid	Fapa	[8]18	18	100.0	--	--	-
Hybrid	Comes	369	251	68.0	22.5	100.0	15
Hybrid	Putr	249	225	90.4	48.1	100.0	11

[1] Species symbols obtained from Plummer and others (1966).

[2] In 1971, 784 seeds from this cross were collected. Only 37 of these seeds were plump and obviously filled; 33 (89.2%) of these plump seeds germinated.

[3] In 1971, 562 seeds from this cross were collected; 362 of these seeds were plump, the rest appeared shriveled. The plump seeds showed a germination percentage of 91.6, whereas surprisingly, 5.5% of the shriveled seeds germinated.

[4] In 1971, 240 of 295 seeds collected from this cross were plump and 236 (97.2%) of the plump seeds germinated.

[5] Only obviously filled seeds counted. Cross made during only 1971.

[6] In 1968, 19 of 133 seeds (14.4%) collected from this cross germinated.

[7] Cross made only during 1970.

[8] Cross made only during 1971.

These results suggest that emasculation is not necessary and that mass pollination of cliffrose flowers just as they begin to open may be sufficient for hybridization. However, the progeny from such crosses should be carefully inspected to identify the ones that may occasionally develop from self-fertilization.

Distribution and Habitat: Stansbury cliffrose is commonly found on dry, rocky foothills and mesas and frequently is associated with pinyon and juniper trees. It is sometimes found at the lower fringes of the ponderosa pine zone at elevations from 1,220 to 2,440 m (4,000 to 8,000 feet) in favorable sites in the big sagebrush (*Artemisia tridentata*), blackbrush, (*Coleogyne ramosissima*), and salt desert shrub types. The distribution of Stansbury cliffrose ranges from southern Colorado to Nevada, Utah, Arizona, southern California, and northern Mexico (Kearney and Peebles 1960). The northernmost population of cliffrose is found in Cache County, Utah. This shrub has

been observed to establish and grow well from plantings in southern Idaho and eastern Washington; but, after 20 years, it is showing some mortality in Idaho. While good see have been produced from these plantings, no natural reproduction has been seen.

Use: Stansbury cliffrose is a highly important winter browse plant for cattle, sheep, and deer. Generally, it is not as palatable as bitterbrush; but on some winter ranges, it is more palatable than bitterbrush--probably because of its more evergreen habit. In southern Arizona, Stansbury cliffrose is not palatable. Accessions from this area have a different two-dimensional chromatogram of phenolic compounds than palatable populations from northern Arizona and central Utah (E. D. McArthur and R. Stevens, 1972. Chromatography information on file at Intermountain Forest and Range Experiment Station, Ephraim, Utah).

Fallugia paradoxa (Apache plume)

Apache plume is a much-branched, often evergreen shrub, 1 to 2 m tall (fig. 25). Leaves are borne in clusters along branchlets. They are pinnately divided into three to seven linear lobes with revolute margins.

The large, white, showy, solitary, perigynous flowers, 25 to 38 mm broad, are usually borne at the ends of slender, elongated peduncles. The typical flower has five sepals that alternate with five supplementary bractlets giving the appearance of 10 sepals, five free-spreading white petals, numerous stamens inserted in three series on the margin of the hypanthium, and numerous pistils.

The numerous short, hairy achenes, 3 mm or less long, produced by this species are tailed by long, reddish plumose persistent styles 25 to 38 mm long (fig. 26). The styles turn white when the seed matures. Apache plume averages approximately 420,000 cleaned seeds per pound (925/g)(U.S. Forest Service 1948).

Figure 25.--Pistillate flower of Apache plume showing nec mature achenes. Note the bagged branch on the left used in hybridization studi

cliffrose X antelope bitterbrush hybrid, antelope bitterbrush.

we have found populations in which the shrubs were mostly monoecious or dioecious. At a site in North Willow Creek Canyon, northwest of Richfield, Utah, at an elevation of [illegible] to a hybridization attempt with some associated cliffrose shrubs. Although all the flowers on the Apache plume were perfect, in that both pistils and stamens were present, some shrubs bore flowers in which the stamens were well developed but the pistils rudimentary and nonfunctional (fig. 27). Other shrubs bore flowers in which the pistils were well developed, but the stamens were rudimentary and nonfunctional (fig. 28). Finally, a majority appeared to be monoecious, bearing both pistillate and staminate flowers. Whether a flower was pistillate or staminate was obvious even in the bud stage when the enclosing petals and sepals were removed. Only a few fully bisexual flowers were found among the Apache plume plants at this locality.

A population of *F. paradoxa* with only perfect and staminate flowers occurs west of Bryce Canyon National Park, Garfield County, Utah, in Red Canyon on the edge of a ponderosa pine type.

The flowering period of Apache plume varies from area to area depending on such factors as elevation and moisture. McMinn (1951) reports floral development from April to June in California, Kearney and Peebles (1960) from April to October in Arizona, and the USDA Forest Service Woody Plant Seed Manual (1948) from June to August. In

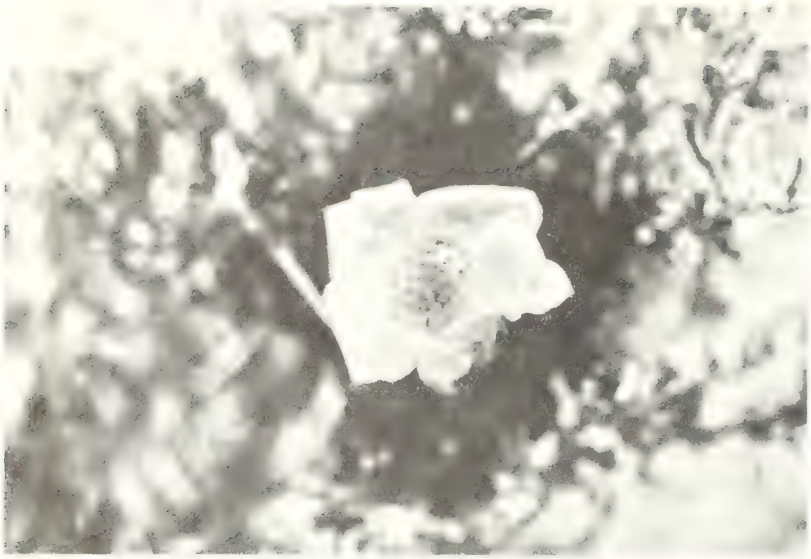

Figure 27.--A staminate Apache plume flower.

Utah, some blooming continues from June to October or until time of frost. There is usually a heavy first blooming that produces more than 90 percent of the annual seed crop. Heavy summer storms can stimulate additional blooming resulting in considerable seed production. However, we have never observed a later seed crop as productive as that of the first blooming.

Ants, hornets, and bees have been observed on Apache plume flowers. We suspect these insects are important factors in the cross-pollination of Apache plume.

Hybridization: During the years 1967-70, some of the pistillate flowers on shrubs located at North Willow Creek Canyon, about 2 miles northwest of Richfield, Sevier

Figure 28.--Pistillate flowers of Apache plume in various stages of development.

County, Utah, were bagged while still in bud to see if they produced [illegible] without pollen being added to the bags. Over 1,200 seeds were produced, but only 5 (0.4 percent) germinated. These viable seeds may have been produced parthenogenetically or the flowers may have produced sufficient pollen to pollinate [illegible] Evidence of self-compatibility was obtained in 1968 when a monoecious branch [illegible] control. It produced 155 seeds of which 31 (20 percent) germinated.

Artificial hybridization attempted by treating pistillate flowers of Apache plume with pollen from cliffrose and antelope bitterbrush (fig. 25) has produced only a few viable seeds and seedlings (table 1). We believe the production of viable seed from these crosses can be improved. Since so few viable seeds were produced using Apache plume as the maternal plant, it was used in 1971 as the pollen source for hybridization of emasculated flowers of bitterbrush, cliffrose, and the cliffrose-bitterbrush hybrid. Better seed production was obtained (table 1). A few putative natural hybrids between this species and cliffrose have been observed in the Kaibab National Forest in Arizona. These hybrids have the Apache plume characteristic of vigorous underground spread, a trait that would be useful in cliffrose and bitterbrush. Certainly, they would be less vulnerable to fire.

Distribution and Habitat: Apache plume occurs in southern California, Nevada, southern and central Utah, Arizona, New Mexico, western Texas, and northern Mexico. It grows best in such deep, moist, rich sites as open canyon bottoms and the sides of arroyos. It occurs, however, in a variety of soils from dry, rocky ridges of the lower brush types through the pinyon-juniper type to the open ponderosa pine belt. Apache plume is most abundant in the southern parts of its range. The northernmost population in Utah was thought to be the one north of Richfield, Sevier County, Utah, in the Willow Creek area; however, in the spring of 1971, a single small Apache plume was found growing about 30 miles further north in the foothills west of Gunnison, Sanpete County, Utah. Apache plume has established well from planting east of Boise, Idaho. Through introduction, this shrub's range could be greatly expanded.

Use: Apache plume is low to fair in palatability. It is important winter forage in the southeastern portion of its range. Apache plume is also an important erosion-control plant in the arid regions where it grows. It is useful for this purpose because it spreads underground vegetatively. Nursery stock and wildings have been planted for erosion control. Where seed sources exist, it spreads naturally to roadside shoulders and barrow pits.

Apache plume is highly fire tolerant. Clumps have been observed to sprout back vigorously after campfires have been built on them. If this strong attribute could be bred into Stansbury cliffrose and antelope bitterbrush, their value for erosion control would be greatly improved.

Peraphyllum ramosissimum (Squawapple)

Squawapple is an intricately-branched shrub to 2 m tall, with deciduous, simple, nearly sessile leaves clustered at the ends of short branchlets (fig. 29). The leaf blades are 12 to 50 mm long and 5 to 9 mm wide. They are light green, glabrous above and paler with minute pubescence below.

The pale-pink, fragrant epigynous flowers are borne solitarily or in clusters of two or three. Flowers are composed of five persistent reflexed sepals, five spreading petals about 8 to 12 mm long, about 20 stamens, and one pistil.

The flowering period of squawapple is from April to July, depending on ecotype, elevation, and climate. The fruit is a small, yellowish, globose, bitter pome about 12 mm or less in diameter at maturity. Squawapple averages 23,750 cleaned seeds per pound (52/g) (Plummer and others 1968).

Figure 29.--Squawapple wit maturing fruit.

Hybridization: Stigmas of young flowers are exserted and appear ready to receive pollen before the anthers of the receptive flowers are open. Mass pollination of bagged flowers just as they begin to bloom may therefore be sufficient for hybridization, particularly if the flowers are self-incompatible. Other species with which squawapple hybridizes naturally are not presently known.

Distribution and Habitat: Squawapple ranges from Oregon to Colorado and Californ The largest populations occur in Utah where it is often an important constituent of th mountain brush. It is found at altitudes from 1,220 to 2,590 m (4,000 to 8,500 feet).

Use: Fruits of squawapple are readily eaten by small mammals, particularly chipmunks and field mice. Birds, deer, and livestock show considerable preference for the apples when they are available. The new twigs and foliage are readily eaten by big game and livestock which may browse on the shrubs in the winter, although other plant species may be preferred (Davis 1952; McKean 1956). Because of durability on severe sites, this shrub might provide valuable rootstocks on which to graft closely related shrubs that are more sensitive to environmental extremes.

Purshia glandulosa (Desert bitterbrush)

Desert bitterbrush in Utah is usually a dense, upright shrub similar in appearanc to Stansbury cliffrose and is often mistaken for it (fig. 30). At higher elevations in California and Nevada, prostrate forms are encountered (Nord 1965). The species ha been regarded as a stabilized hybrid between antelope bitterbrush and cliffrose (Thomas 1957; Stebbins 1959; Stutz and Thomas 1964; Stutz 1974). The evergreen leaves are dark green, nearly hairless, and dotted with impressed glands on the inrolled edge Leaves are cleft into 3-5 linear lobes.

The yellow to sometimes cream-colored flowers are showy and about 20 mm broad on second-year or older growth. Each flower has five persistent petals, about 25 stamens and usually two or three pistils.

The persistent receptacle is downy haired or woolly, resinous, and dotted below. Fruits are oblong achenes protruding from the receptacle. Usually three, but sometime two, fruits are produced. The fully developed fruit is 5 to 20 mm long, hard and leathery, and slightly grooved, tapering to a beak that is a vestigial plume in some

Figure 30.—Large desert bitterbrush surrounded by blackbrush near Motoqua, Washington County, Utah.

instances. The seed has a smaller diameter than [illegible] bitterbrush. Desert bitterbrush averages 20,800 cleaned seeds per pound (46/g) (Plummer and others 1968).

In Utah, flowers bloom in May with the first [illegible] tions and by mid-August at higher elevations. Blooming and seed maturity occur earlier on more southerly ranges. However, in California, blooming has been observed as late as August at elevations of 2,740 m (9,000 feet).

Hybridization: Natural hybrids between desert bitterbrush and antelope bitterbrush or Stansbury cliffrose are common in areas where the species occur together. Stebbins (1959) reports that desert and antelope bitterbrush form such extensive hybrid swarms in eastern California where their ranges overlap that identity of their parental types is completely obliterated.

Purshia glandulosa has $n = 9$ chromosomes (H.C. Stutz, Professor of Botany and Range Science, Brigham Young University, Provo, Utah, personal communication).

Distribution and Habitat: Desert bitterbrush is found in southern Nevada, southern California, northwestern Arizona, and southwestern Utah. It normally occurs on drier sites than antelope bitterbrush; however, there are major zones of overlap. At lower elevations in southwestern Utah, desert bitterbrush is associated with blackbrush and Stansbury cliffrose and at higher elevations, with big sagebrush, antelope bitterbrush, and Saskatoon serviceberry.

Use: Desert bitterbrush is an important browse plant throughout its range. It is usually less palatable than antelope bitterbrush, but more palatable than Stansbury cliffrose (Sampson and Jespersen 1963).

Desert bitterbrush readily sprouts following burning. Shoots are formed from deeply embedded roots, which make desert bitterbrush particularly valuable in stabilizing roadcuts and similar surfaces where several feet of topsoil have been removed (fig. 31). This shrub is especially recommended for restoration of mine spoil areas and other seriously disturbed sites because of its sprouting characteristics and ability to grow in soils of low fertility. Ecotypes with a wide range of adaptation are being sought for use in the revegetation of widely scattered disturbed areas.

Figure 31.--Desert bitterbrush growing on a raw roadcut east of Independence, Inyo County, California. These plants sprouted from roots exposed by road construction.

Purshia tridentata (Antelope bitterbrush)

Antelope bitterbrush is an intricately branched shrub varying in stature from low prostrate forms (fig. 32) to erect arborescent forms as tall as 4.6 m (fig. 33). The branches of prostrate forms often root when in contact with the ground (fig. 34). This layering characteristic is common in prostrate bitterbrush throughout much of its range. It is a common understory shrub in ponderosa pine and lodgepole pine (*Pinus contorta*) types. In general, layering forms show much greater tolerance to fire than do upright nonlayering forms. Fire tolerance in bitterbrush is a valuable trait.

The yellow flowers are perigynous, perfect, showy, about 8 mm broad, and usually solitary on short, lateral branchlets. Each flower has five persistent sepals, five pale-yellow, spreading petals, about 25 stamens inserted on the hypanthium in one series, and one or occasionally two pistils (fig. 35).

The leathery, oblong, pubescent achene is about 5 to 12 mm long and is tipped by a persistent tapering style (fig. 35).

Figure 32.--Prostrate form of antelope bitterbrush common over much of the West, particularly in the mountain brush and the ponderosa pine zones.

Figure 33.--Giant arborescent form of [illegible] of Mt. Pleasant, Sanpete [illegible] population has obviously [illegible] from cliffrose.

Figure 35.--Comparison of [illegible] brush-cliffrose complex: (1) typical bitterbrush receptacles with one or [illegible]; (2) [illegible] bitterbrush receptacles with five to seven achenes; (3) typical bitterbrush X cliffrose hybrid receptacles each with two or three [illegible]; (4) cliffrose receptacles each with four or five plumed achenes.

Flowers bloom from April to July and fruits ripen from July to September. The effect of elevation on the rate of flower and fruit development of most shrubs is well illustrated by the following examples. Bitterbrush was in early fruit June 18, 1967, at Pigeon Hollow in Sanpete County, Utah, 1,520 m (5,000 feet); it was in all stages o flowering at Oaks Climatic Station in Ephraim Canyon, Utah, 2,380 m (7,800 feet); and it was still in bud at Snowberry in Ephraim Canyon, 2,560 m (8,400 feet).

Study of floral phenology indicated that the stigmas and stamens reach maturity about the same time. A variety of bees and wasps frequent the blossoms, and ants, aphids, and cicadas have also been found. Evidently, insects are important in the pollination of the flowers in nature. Cicadas, however, may do considerable damage in high population years. Wounds are made on twigs and branches by the ovipositor when the eggs are deposited. Bitterbrush populations suffer occasional damage from tent caterpillars. Antelope bitterbrush averages 15,400 cleaned seeds per pound (34/g) (Plummer and others 1968).

Hybridization: Antelope bitterbrush crossed with cliffrose or desert bitterbrush produces fertile hybrids in nature (fig. 22 and 26). Hybridization between antelope bitterbrush and cliffrose is very common throughout Utah where their ranges overlap. Also, many F_2 and backcross segregants are common. Careful examination reveals cliffrose traits in most populations of bitterbrush in the region. Evidently, sympatric introgression is widespread between the two parent species. The hybrids have n = 9 chromosomes as do both parents (Stebbins 1959).

Viable seeds and seedlings which resemble the many natural hybrids have been obtained by artificially pollinating emasculated flowers of bitterbrush with pollen from cliffrose (fig. 36) and the cliffrose-bitterbrush hybrid (table 1). During the 1971 season, 19 plump, obviously filled seeds were obtained by using Apache plume (*Fallugia paradoxa*) pollen on emasculated bitterbrush flowers (table 1).

Viable seed has also been obtained when bitterbrush pollen was artificially appli to emasculated flowers of Stansbury cliffrose, the cliffrose and bitterbrush hybrid, and the pistillate flowers of Apache plume (table 1).

Most antelope bitterbrush evidently is self-incompatible. This conclusion was drawn since 17 bagged branches containing unemasculated bitterbrush flowers set only four viable seeds over a 4-year period. These four seeds were all produced on the sam branch in 1970. Mass pollination of bitterbrush flowers just as they begin to open is probably sufficient for hybridization since results from the bagged, emasculated controls suggest that emasculation is not necessary. Considerable time will be saved by not having to emasculate each flower. Also, pistils will mature more seed because they will not be damaged during emasculation procedures.

Antelope bitterbrush is reported to have a chromosome number of n = 9 (Thomas 1957; Stebbins 1959).

Distribution and Habitat: Antelope bitterbrush normally occurs in well-drained, sandy, gravelly, or rocky soils throughout the sagebrush, juniper-pinyon, mountainbrus ponderosa pine, and lodgepole pine types at elevations from 60 m (200 feet) in the Pacific Northwest to 3,510 m (11,500 feet) in the Sierra Nevada Mountains (Stanton 195 Nord 1965). In Utah, bitterbrush does occur on some clay loams where deeper rock stra furnish good drainage, and at least one form grows on a deep basic-clay loam where drainage is poor. A prostrate form grows on deep acid-clay soils in Oregon. Bitterbrush's range extends over much of temperate western America from California eastward throughout the Rocky Mountains and from British Columbia southward to Arizona and New Mexico (McMinn 1951; Stanton 1959; Hitchcock 1961).

Figure 36.--A vigorous seedling hybrid produced by pollinating emasculated flowers of a prostrate, layering antelope bitterbrush with pollen from cliffrose.

Use: Antelope bitterbrush is one of the most important browse plants in the West for game animals, sheep, and cattle. Its fall and winter protein content helps to offset protein deficiency during these seasons when herbaceous vegetation has dried up (Hormay 1943; Dietz 1972). Bitterbrush also lengthens the grazing season by providing forage 4 to 6 weeks longer in the fall than the herbs. Ferguson (1972) found that forage production can be increased considerably by topping mature plants (fig. 37). Topping can be accomplished mechanically or by grazing the stand periodically with cattle (Hormay 1943). In Utah, elk have been observed to be efficient in topping bitterbrush, particularly in periods of deep snow. This shrub is virtually unsurpassed in its ability to maintain itself under severe grazing conditions.

Antelope bitterbrush is relatively much more important and abundant in California, Idaho, Oregon, and Washington than other western States. Hitchcock and others (1961) rated *P. tridentata* as a choice ornamental for any area east of the Cascades. Layering forms are useful in stabilizing and beautifying roadcuts and other exposed sites (fig. 38). Because of its ability to grow on depleted soils and severe sites, it is an outstanding shrub for stabilizing disturbed sites.

Figure 37.--Bitterbrush topped to increase production of available forage.

Figure 38.--Antelope bitterbrush growing on road cut in Utah County, 5 miles north of Eureka, Juab County, Utah.

Rose woodsii (Woods rose)

Woods rose is a prostrate to upright shrub from 0.5 to 3.0 m tall (fig. 39). The opposite compound leaves are composed of five to 11 leaflets which are oval, elliptic, or obovate in shape, with serrate margins. The leaflets range in size to 2.5 by 5.0 cm. Stem and branches from area to area have varying numbers of prickles. On some ecotypes, prickles are almost totally missing, whereas on others high densities are present (fig. 40).

Figure 39.--An upright woods rose. The scale is in feet.

Figure 40.--Woods rose cuttings from different accessions showing variation in prickliness. Note the hips on the cutting second from right.

Light-pink to deep-rose colored flowers are borne on lateral shoots from old wood which are usually over 10 cm long. Flowers are rarely solitary, usually there are fou or more in a corymbiform cyme. The five persistent sepals are from 1 to 2 cm long, 2 to 3.5 mm wide at base. The tip of each sepal is usually a little expanded above the median constriction. The sepals are erect or spreading in fruit. Woods rose petals are five in number and 1.0 to 2.5 cm long. Stamens and pistils are numerous. The capitate stigmas form a cluster closing the mouth of the hypanthium. Blooming occurs from late spring through midsummer, varying considerably according to elevation and exposure.

The fleshy globose to ellipsoid fruit (hip)[1] (fig. 40) is 6 to 15 mm wide and up to 2.0 cm long and contains 15 to 30 achenes. Each achene is 3 to 4 mm long with stif hairs along one side. Wood rose averages 45,300 cleaned seeds per pound (100/g) (Plummer and others 1968).

Woods rose exhibits much variation in growth habit, number of prickles, vegetativ spread, and drought tolerance. Some authorities, among them Hitchock and others (1961 recognize two varieties. Under this treatment, variety *ultramontana* is the prevalent one in the Intermountain area. Variety *woodsii* is the common woods rose on the plains and prairie east of the Rocky Mountains. Even within varieties there is substantial variation.

Hybridization: The genus *Rosa* is a natural plant assemblage. Its species, how- ever, are often difficult to distinguish (Erlanson 1934; Harrington 1954). Many of th wild roses of western North America hybridize (Hitchcock and others 1961). Improved stock for planting purposes could be obtained by selection and breeding of the richly variable woods rose and its relatives.

The chromosome number of woods rose is $2n = 14$ (Hitchcock and others 1961).

Distribution and Habitat: Woods rose is widely distributed in western Canada and the western United States. It is found from valley floors to alpine sites, 1,070 to 3,320 m (3,500 to 11,000 feet). It is most abundant in such moist places as along str banks, but is also found in relatively dry habitats on mountain ranges. It flourishes in moderate shade to full sunlight and so makes good growth on all aspects. Woods ros is seldom found where the average annual precipitation is less than 260 mm (12 inches)

Use: Woods rose is browsed in all seasons by livestock and big game; however, heaviest use is in the early spring and in the fall. Forms having few or no prickles are generally preferred, but a high density of prickles has a survival value, preserv- ing plants from being too heavily grazed. Even the heavily prickled populations some- times receive substantial use. The persistent hips provide food for birds and upland game species in the winter when little other food is available.

Some ecotypes of woods rose spread aggressively by root sprouting. These are excellent for soil stabilization. It is readily established on roadcuts and fills fro both nursery stock and wildings. Results from direct seeding have been variable but, no doubt, can be improved.

[1] Accessory fruit formed by the fleshy calyx enclosing the true fruits, the achenes.

REFERENCES

Benson, L., and R. A. Darrow
1944. A manual of southwestern desert trees and shrubs. Univ. Ariz. Biol. Bull. 6. 411 p.

Clausen, J., D. D. Keck, and W. M. Heisey.
1940. Experimental studies on the nature of species. Carnegie Inst. Wash. Publ. 520. 452 p.

Cruise, J. E.
1964. Studies of natural hybrids in *Amelanchier*. Can. J. Bot. 42:651-663.

Davis, R. J.
1952. Flora of Idaho. Wm. C. Brown Co., Dubuque, Iowa. 828 p.

Dietz, D. R.
1972. Nutritive value of shrubs. *In*: McKell, C. M., J. P. Blaisdell, and J. R. Goodin, eds., Wildland shrubs - their biology and utilization, p. 289-302. USDA For. Serv. Gen. Tech. Rep. INT-1. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Drobnick, R., and A. P. Plummer.
1966. Progress in browse hybridization in Utah. Proc. Conf. West. State Game and Fish Comm. 46:203-211.

Erlanson, E. W.
1934. Experimental data for a revision of the North American wild roses. Bot. Gaz. 96:197-256.

Ferguson, R. B.
1972. Bitterbrush topping: shrub response and cost factors. USDA For. Serv. Res. Pap. INT-125, 11 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Harrington, H. D.
1954. Manual of the plants of Colorado. 666 p. Sage Books, Denver.

Hitchcock, C. L., A. Cronquist, M. Ownbey, J. W. Thompson.
1961. Vascular plants of the Pacific Northwest. Part 3: Saxifragaceae to Ericaceae. 614 p. Univ. Wash. Press, Seattle.

Hoeppel, R. E., and A. G. Wollum II.
1971. Histological studies of ectomycorrhizae and root nodules from *Cercocarpus montanus* and *Cercocarpus paucidentatus*. Can. J. Bot. 49:1315-1318.

Holmgren, A. H.
1974. Shrubs in Utah and the Intermountain region. Utah Sci. 35:3-4.

Holmgren, A. H., and J. L. Reveal.
1966. Checklist of the vascular plants of the Intermountain region. USDA For. Serv. Res. Pap. INT-32, 160 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Hormay, A. L.
1943. Bitterbrush in California. USDA For. Serv. Calif. For. and Range Exp. Stn. Res. Note 34, 13 p.

Jones, G. N.
1946. American species of *Amelanchier*. Ill. Biol. Monogr. 20(2), 126 p.

Kearney, T. H. and R. H. Peebles.
1960. Arizona Flora. 2nd ed. 1085 p. Univ. Calif. Press, Berkeley and Los Angeles.

Krebill, R. G. and J. M. Muir.
1974. Morphological characterization of *Frankia purshiae*, the endophyte in root nodules of bitterbrush. Northwest Sci. 48:266-268.

McArthur, E. D., B. C. Giunta, and A. P. Plummer.
1974. Shrubs for restoration of depleted ranges and disturbed areas. Utah Sci. 35:28-33.

McKean, W. T.
1956. Winter guide to native shrubs of the central Rocky Mountains. 273 p. Colo. Dep. Fish and Game. Hirschfield Press, Denver.
McMinn, H. E.
1951. An illustrated manual of California shrubs. 663 p. Univ. Calif. Press, Berkeley and Los Angeles.
Nord, E. C.
1965. Autecology of bitterbrush in California. Ecol. Monogr. 35:307-334.
Plummer, A. P.
1974. Morphogenesis and management of woody perennials in the United States, p. 72-80. In: Plant morphogenesis as the basis for scientific management of range resources. USDA Agric. Res. Serv. Misc. Publ. 1271, 232 p.
Plummer, A. P., D. R. Christensen, and S. B. Monsen.
1968. Restoring big-game range in Utah. Utah Div. Fish and Game Publ. 68-3, 183
Plummer, A. P., R. L. Jensen, and H. D. Stapley.
1957. Job completion report for game forage revegetation project W-82-R-2. Utah State Dep. Fish and Game Inf. Bull. 1956-1957, 128 p.
Plummer, A. P., S. B. Monsen, and D. R. Christensen.
1966. Intermountain range plant symbols. 69 p. USDA For. Serv. Intermt. For. a Range Exp. Stn., Ogden, Utah.
Pyrah, G. L.
1964. Cytogenetic studies of *Cercocarpus* in Utah. 44 p. M.S. thesis, Brigham Young Univ., Provo, Utah.
Sampson, A. W., and B. S. Jespersen.
1963. California range brushlands and browse plants. Calif. Agric. Exp. Stn. Ex Serv. Man. 33, 162 p.
Stanton, F. W.
1959. Autoecological studies of bitterbrush (*Purshia tridentata* [Pursh] DC.) 188 Ph.D. Diss., Oregon State Univ., Corvallis.
Stebbins, G. L.
1959. The role of hybridization in evolution. Proc. Am. Philos. Soc. 193:231-25
Stutz, H. C.
1974. Rapid evolution in western shrubs. Utah Sci. 35:16-20, 33.
Stutz, H. C., and L. K. Thomas.
1964. Hybridization and introgression in *Cowania* and *Purshia*. Evolution 18:183-
Thomas, L. K.
1957. Introgression in *Purshia tridentata* (Pursh) DC. and *Cowania stansburiana* Torr. 66 p. M.S. thesis, Brigham Young Univ., Provo, Utah.
Thompson, R. M.
1970. Experimental top pruning of curlleaf mahogany trees. USDA For. Serv., Intermt. Reg., Ogden, Utah. Range Improv. Notes 15(3):1-11.
Tidestrom, I.
1925. Flora of Utah and Nevada. Contrib. from U.S. Nat. Herb. 25:1-665.
Tidestrom, I., and T. Kittrell.
1941. A flora of Arizona and New Mexico. 897 p. Catholic Univ. Am. Press, Washington, D.C.
USDA Forest Service.
1937. Range plant handbook. 841 p. U.S. Gov. Print. Off., Washington, D.C.
USDA Forest Service.
1948. Woody plant seed manual. 416 p. U.S. Dep. Agric. Misc. Publ. 654. U.S. Gov. Print. Off., Washington, D.C.
Webster, S. R., C. T. Youngberg, and A. G. Wollum II.
1967. Fixation of nitrogen by bitterbrush (*Purshia tridentata* [Pursh] DC.) Natur 216:392-393.
Welsh, S. L. and G. Moore.
1973. Utah plants, tracheophyta. 474 p. Brigham Young Univ. Press, Provo, Utah
West, N. E.
1974. Shrublands of Utah. Utah Sci. 35:4-6.

APPENDIX

Key to Genera and Species

1a. Ovary inferior, adnate to the hypanthium; fruit a pome.
  2a. Leaves sessile or nearly so, alternate but fascicled at the ends of the branchlets; flowers solitary or two to three together; styles two. . .*Peraphyllum ramosissimum*
  2b. Leaves petioled, not fascicled at ends of branchlets; flowers mostly several to many in a raceme; styles two to five. . . . . *Amelanchier*
    3a. Leaves mostly glabrous at maturity; petals usually more than 10 mm long; styles usually five; fruit glabrous, 10-15 mm in diameter, normally with 10 locules . . . . . *A. alnifolia*
    3b. Leaves finely pubescent; petals usually less than 10 mm long; styles two to four (rarely five); fruit frequently pubescent, 6-10 mm in diameter, with three to six locules. . . . . *A. utahensis*
1b. Ovary superior, not adnate to the hypanthium, fruit an achene.
  4a. Flowers inconspicuous; petals lacking. . . *Cercocarpus*
    5a. Leaves deciduous, flat; margins dentate . . . . . [illegible]
    5b. Leaves evergreen, somewhat revolute; margins entire or dentate.
      6a. Leaves, at least some, with margins dentate; a hybrid . . . . [illegible]
      6b. Leaves entire, usually strongly revolute.
        7a. Leaves elliptic, over 12 mm long; plants tall shrubs or small trees. . . . . [illegible]
        7b. Leaves linear to narrowly oblong, usually less than 12 mm long; plants low, intricately branched shrubs . . . . . *C. intricatus*
  4b. Flowers showy; petals present.
    8a. Leaves pinately compound; achenes enclosed in the fleshy calyx tube . . . . . *Rosa woodsii*
    8b. Leaves simple; achene(s) not enclosed in a fleshy calyx tube.
      9a. Bractlets present at base of flower; pistils more than 12 . . . . . *Fallugia paradoxa*
      9b. Bractlets absent; pistils less than 12.
        10a. Pistils four or more; styles becoming elongated and plumose; leaves usually with five or more lobes . . . . . *Cowania mexicana* var. *stansburiana*
        10b. Pistils less than four; style not markedly elongated or plumose; leaves usually with five or less lobes.
          11a. Pistils two to three; style slightly elongated or plumose; leaves usually with three to five lobes; a hybrid . . *Cowania mexicana* var. *stansburiana* X *Purshia tridentata*

11b. Pistils one to two; styles short and tapering to tip; not plumose; leaves usually with three lobes . . *Purshia*

12a. Leaves three-toothed, pubescent, usually deciduous; flowers about 8 mm broad. . . . *P. tridentata*

12b. Leaves three- to five-toothed, nearly hairless, dotted with impressed glands; evergreen, flowers about 20 mm broad . *P. glandulosa*

BLAUER, A. CLYDE, A. PERRY PLUMMER, E. DURANT McARTHUR, RICHARD STEVENS, and BRUCE C. GIUNTA.

1975. Characteristics and hybridization of important Intermountain shrubs. 1. Rose family. USDA For. Serv. Res. Pap. INT-169. 55 p. (Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.)

This paper reviews the state of knowledge, records observations, and presents original data for important Intermountain rosaceous shrubs. Major emphasis is given to the recognition of taxa. Each species treated is described and its hybridization, distribution and habitat, and uses are reviewed. Pioneer hybridization studies on the compatible genera Cowania, Cercocarpus, Fallugia (Apache plume), and Purshia (bitterbrush) are presented.

OXFORD: 181.1:165.71.

KEYWORDS: distribution, hybridization, hybrids, rosaceous shrubs, habitat, uses, Amelanchier, Cercocarpus, Cowania, Fallugia, Purshia, Rosa.

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GROWING

DETERIORATION OF ASPEN CLONES IN THE MIDDLE ROCKY MOUNTAINS

George A. Schier

NOV 24 1975

USDA Forest Service
Research Paper INT-170
1975

INTERMOUNTAIN FOREST AND
RANGE EXPERIMENT STATION
Ogden, Utah 84401

THE AUTHOR

GEORGE A. SCHIER, Plant Physiologist, stationed at the Forestry Sciences Laboratory in Logan, Utah, joined the Intermountain Station staff in 1969. He holds the bachelor of science degree in forestry from the University of New Hampshire, the master of forestry degree from Yale University, and the doctoral degree in woody plant physiology from the University of Michigan. He has published numerous articles on the vegetative regeneration of aspen.

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DETERIORATION OF ASPEN CLONES IN THE MIDDLE ROCKY MOUNTAINS

George A. Schier

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401
Roger R. Bay, Director

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ABSTRACT

The frequent failure of deteriorating aspen (Populus tremuloides Michx.) clones to regenerate vegetatively by root suckers was studied by comparing the suckering capacity of these clones with adjacent healthy clones. Sucker production from root cuttings was used to evaluate the suckering capacity of a clone. Scarcity of regeneration in deteriorating clones was found to be unrelated to the ability of roots to sucker. A hypothesis based on the apical dominance phenomenon is presented to account for the low numbers of suckers produced by deteriorating clones. Stand data, sucker densities, and root ages of the clones are compared. Aspects of aspen deterioration discussed include relationship between deterioration and genotype, role of pathogens including viruses, and possibilities of revitalizing deteriorating clones by cultural methods.

INTRODUCTION

Before development of a fire suppression program in the Intermountain region, wildfires played an important role in the ecology of aspen (*Populus tremuloides* Michx.) (Loope and Gruell 1973). Frequent fires perpetuated the species because aspen is especially adapted to reproducing itself after its aboveground parts have been killed. Stands are regenerated vegetatively by adventitious shoots (suckers, or ramets) that originate irregularly on living roots. As a result of successive generations of shoots arising from a continually expanding root system, aspen occurs in large clones of genetically identical individuals (Barnes 1966).

When fire and other major disturbances are excluded from the environment, the ramets of a clone become mature in 80 to 100 years and then show a rapid decline in vigor and increasing susceptibility to disease and insects with advancing age.

Deterioration is first evidenced by permanent openings in the canopy created by the death of individual stems. In a relatively short time, a scattering of diseased stems will be all that remains of a clone (fig. 1). On many sites, deteriorating aspen clones are replaced by conifers. Dry sites often revert to rangeland dominated by shrubs, forbs, and grasses (fig. 2). Sucker reproduction usually occurs beneath a deteriorating overstory, but often shoot numbers are insufficient to replace the mortality. Reproduction from seed does occur (Every and Weins 1971), but is rare, primarily because the seed remains viable only a short time and because the environment is usually too dry for seedling establishment (Barnes 1966).

Aspen deterioration is widespread throughout the Intermountain region. The ramets of most aspen clones within the region had their origin during the 19th century, before successful fire suppression. Many clones are reaching maturity; so we should see an increase in the number deteriorating during the next decade. Because aspen provides valuable watershed protection, is important as big game habitat and as summer range for livestock, has many esthetic values and potential for utilization in wood products, its future is a major concern of the resource manager.

Although the general pattern of aspen deterioration has been described in eastern (Graham and others 1963; Fralish 1972) and in western (Krebill 1972; Loope and Gruell 1973; Gruell and Loope 1974) States, no one has adequately explained why the production of root suckers is often insufficient to replace overstory mortality in decadent aspen clones. The purpose of this study was (1) to investigate the capacity of overmature aspen to produce root suckers and (2) to develop a hypothesis that would account for the scarcity of regeneration in deteriorating clones compared to the usually abundant reproduction that follows logging or fire.

1946

1965

Figure 1.--Photographic record of aspen deterioration on the Beaverhead National Fores Montana. The 1946 photo shows overmature aspen with young aspen in the understor (lower right quarter). Nineteen years later, most of these aspen have disappeare In contrast, the small and the large clone in the lower left quarter of both phot have thinned out but have maintained themselves.

Figure 1.--An aspen clone in the Gros Ventre Range of the Bridger-Teton National Forest, Wyoming. The clone once supported a continuous crown cover over several hectares. The site has reverted to rangeland dominated by shrubs, forbs, grasses, and decaying aspen remnants. Heavy browsing by elk hastened this transition.

Figure 3.--Healthy and deteriorating aspen clones used in this study. Fall photos were used to emphasize number of stems.

Table 2.--*Density of sucker regeneration in healthy and deteriorating clones expressed in number of individual suckers and in number of sucker clumps*

Pair	Healthy clones			Deteriorating clones		
	Suckers[1] per ha	Clumps[2] per ha	Frequency (percent)	Suckers per ha	Clumps per ha	Frequency (percent)
1	7,200	2,400	80	820	640	50
2	3,500	1,900	50	1,010	640	65
3	2,300	1,500	30	1,090	690	60
4	6,200	3,800	70	520	400	40
5	7,100	2,200	50	395	270	40

[1] D.b.h. smaller than 2 cm.
[2] Maximum area covered by a clump did not exceed a circular area 20 cm in diameter.

Sucker regeneration in healthy clones was relatively high compared to that in deteriorating clones (table 2). As in the deteriorating clones, numbers of individual suckers gave an inflated estimate of sucker reproduction and frequency data indicated that regeneration was not uniformly distributed throughout the clone. More than 50 percent of the suckers were less than 10 cm in height. Incidence of shoot dieback among suckers was common in the healthy clones.

Results from testing suckering capacity of root cuttings collected from healthy and deteriorating clones (table 3) indicated no clear-cut relationship between deterioration and ability to sucker. Of the deteriorating clones tested, two produced significantly fewer suckers than their healthy counterparts and two produced about the same number; one produced significantly more suckers than the healthy clone with which it was paired.

Table 3.--*Mean number of suckers (>5mm) produced from root cuttings (10 by 1 to 2cm) from healthy and deteriorating aspen clones and mean age of roots used; suckers were counted after a 42-day propagation period*

Pair	Healthy clones		Deteriorating clones		Significant[1] difference in suckering
	Suckers per cutting	Root age (yrs)	Suckers per cutting	Root age (yrs)	
1	10.8	21.6	1.6	14.2	**
2	11.9	16.7	2.7	15.4	**
3	9.5	24.4	14.4	16.2	N.S.
4	7.0	15.0	21.8	10.8	**
5	14.3	10.4	18.6	9.6	N.S.
Av.	10.7	17.6	11.8	13.2	

[1] Determined by "t" tests: N.S.--nonsignificant; **--significant at p = 0.01.

Mean age of roots in the 1- to 2-cm-diameter class are shown in table 3. Differences in suckering capacity between clones in a healthy-deteriorating clone pair did not appear to be related to root age. Mean ages of roots from deteriorating clones were lower than those from healthy clones. A "t" test for paired replicates indicated that age differences were significant at the 5 percent level.

Necrotic areas were found in the bark of many roots of the deteriorating clone of pair 2 (fig. 3). These would seriously impair sucker formation because adventitious shoots are initiated in the region of the cork cambium. The number and size of necrotic areas on roots appeared to increase with root diameter (that is, age); so it seemed likely that sucker numbers would be inversely related to diameter. This was found to be true. Cuttings 1 to 1.5 cm (average age, 12.9 years) in diameter produced 5.9 suckers per cutting while those 1.5 to 2.0 cm (average age, 18.0 years) in diameter produced 1.1. The healthy clone of the pair showed no significant difference in sucker production between the two size classes.

DISCUSSION

Scarcity of regeneration in the deteriorating aspen clones used in this study does not appear to be related to suckering capacity of the roots. Although greenhouse tests showed that roots of some deteriorating clones produce relatively few suckers compared to their healthy counterparts, roots of others produced about the same or significantly more suckers than the healthy clones. Therefore, we must look for reasons in addition to loss in suckering capacity to account for poor sucker reproduction in deteriorating aspen clones.

The following is a hypothesis developed by the author to explain why regeneration is generally unsuccessful in deteriorating aspen clones. It was developed from the results of this study and from a general knowledge of the physiological mechanisms controlling sucker development:

> In healthy and in deteriorating aspen clones, auxin produced in shoots is translocated downward into roots where it inhibits sucker formation, a phenomenon known as apical dominance (Farmer 1962; Eliasson 1971a, 1971b; Schier 1973b, in press; Steneker 1974). Interference with this auxin supply changes hormone balances in roots enabling other hormones and such growth promoters as cytokinins to initiate regenerative processes.
>
> When the diseased overmature stems in deteriorating clones weaken and die, the root system dies back because the amount of photosynthate channeled to the roots is decreased by reduction in crown area. Residual stems maintain auxin levels in the smaller root system; so sucker production continues to be generally inhibited.

Mortality finally reduces the density in deteriorating clones to a scattering of overmature stems. Rate of decline depends on site, genotype, presence of competing vegetation, and browsing intensity by big game and livestock. Reduced clone vigor predisposes stems and roots to attack by various pathogens. At some stage, disease and reduced levels of carbohydrate reserves affect the suckering capacity of roots. It is then problematical how long a clone will continue to survive. As long as some roots are present and adventitious shoots are initiated and can grow into larger stems, ramets will maintain a clone in a given area.

A few suckers arise in deteriorating clones as they do in healthy clones because of various disturbances (Schier 1973a). Damage to roots by livestock and wildlife, insect and disease attacks, and even subtle environmental changes cause localized shifts in the hormone balance between growth promoters and inhibitors in roots, which triggers sucker formation.

However, after suckers are formed they are not free to develop unimpeded. Sucker growth is likely to be suppressed to varying degrees by apical dominance of the overstory. Environmental conditions for sucker growth are most suitable in open deteriorating clones because enough solar radiation reaches the forest floor. In healthy clones, low light intensity represses sucker growth. In addition, the humid environment is suitable for dieback fungi that attack the succulent shoots of young suckers.

Others have suggested that the appearance of suckers under an aspen canopy is idence against an apical dominance theory. The suggestion ignores the fact that hibition is not absolute and can be modified by a number of environmental factors.

It was interesting that aging of roots in the 1- to 2-cm-diameter class, the size nge used for sucker propagation, indicated that roots of deteriorating clones were gnificantly younger than those from healthy clones. Possibly, in a root system that dying back, older, less vigorous roots would be the first to die, which would tend lower the mean age of remaining roots.

It is not unusual, as in this study, to find a deteriorating clone adjacent to a ealthy one, ramets of both probably having been established at about the same time. ie close relationship between deterioration and clone characteristics suggests that enotype may be the controlling factor in the timing and rate of decline.

Aging, which is manifested by reduced growth, a decrease in metabolism, an increase in dead branches, and lower resistance to disease and insects, may occur at a ore rapid rate in some genotypes than others. Clonal differences in susceptibility pathogens (Mielke 1957; Wall 1971; Copony and Barnes 1974) and insects may also count for variation in clone condition. One would also expect clones with inherently oor suckering capacity to be less able to reproduce during deterioration than those th high suckering capacity.

There may even be genotypes in which apical control is weak or the level of growth-aitiating factors is high so that stands sucker vigorously at the least disturbance ig. 4). The uneven-aged ramets of many selected clones that Alder (1970) studied in tah and northern Arizona indicate there are clones in which mortality is quickly replaced by adventitious shoots.

The abundant production of suckers that usually follows logging, fire, or any her major disturbance that kills all or most stems within a short time demonstrates

Figure 4.--The abundance of suckers in this understory of overmature ramets demonstrates that some clones sucker profusely during deterioration (Wasatch National Forest, Utah). There were no signs of a major disturbance that could have stimulated suckering. Ramets of this clone have good form and low branchiness. In contrast, the deteriorating clones used in this study have a ratty appearance (see fig. 3).

that regeneration is usually no problem when an aspen stand is wiped out relatively fast. The rapid death of stems eliminates apical dominance while the original root system can still produce suckers.

However, it is not unusual to find large numbers of suckers in the understory of diseased aspen. Pathogens may stimulate suckering by affecting auxin metabolism or transport. Stands attacked by aspen leaf blight (*Marssonina populi* [Lib.] Magn.), to which aspen shows a high clonal variation in susceptibility (Mielke 1957), often have well-established regeneration. Figure 5 shows the scattered remnants of an aspen clone (first observed by Tew [1967], his clone 1) after a series of attacks by *Marssonina* over about 10 years and the young stand that has become established in the understory. The blight does not appear to be causing mortality in the regeneration. Sprouting is vigorous beneath the thin overstory of mature aspen stands in Wyoming that are dying out in the presence of viruslike symptoms (personal communication, Dr. W. D. Ross, University of Wyoming, Laramie).

Insect outbreaks also cause the development of suckers in the understory of mature aspen. Defoliation of aspen in interior Alaska from 1965 to 1968 by the large aspen tortrix (*Choristoneura conflictana* Walker) resulted in suckering in some clones before the growth of new leaves (personal communication, Dr. J. C. Zasada, USDA Forest Service, Institute of Northern Forestry, Fairbanks, Alaska).

igure 5.--Mortality has been heavy in this clone because of repeated attacks by Marssonina populi *(Wasatch National Forest, Utah). The actual cause of mortality may have been caused by a secondary pathogen that attacked weakened trees. The blight apparently has reduced the effects of apical dominance which has resulted in abundant sucker production.*

To revitalize a deteriorating aspen clone, treatment must stimulate suckering. uckering can be promoted by killing stems in such various ways as by clearcutting, ontrolled burning, or herbicide spraying. Deteriorating clones probably vary in heir potential for producing regeneration because of clonal variations in suckering apacity (Schier 1974), and differences in root density and site factors. When all hat remain of a stand are a few scattered, widely spaced stems, the roots necessary or producing a uniformly dense stand of suckers are not present. Root density has robably declined to such an extent that, after the clone is treated, regeneration ill consist of small groups of suckers in the vicinity of stumps or dead stems. In ime, these groups may increase in size as roots grow into the intervening spaces and epeated generations (rotations) of raments are produced by periodic killing of stems.

Another regeneration problem could result from the effects of pathogens in residual rees. These may seriously reduce root suckering capacity and sucker growth.

Other important regeneration problems are caused by competing vegetation and rowsing by livestock and wildlife. Heavy browsing on elk winter ranges can totally uppress regeneration and speed up succession by conifer types or shrub, grass, and orb communities (Krebill 1972; Gruell and Loope 1974). Often, however, when aspen ails to regenerate there is a tendency to blame livestock and wildlife without in- estigating. This paper has shown that physiological mechanisms inherent to the clonal rowth habit of aspen can prevent sucker production.

The role of viruses is an interesting aspect of aspen deterioration. The reader should bear in mind that little is known about the occurrence of viruses in aspen; so this discussion is largely speculative.

An unknown factor in aspen deterioration is the effect of clone age as distinct from ramet ages. The large size of aspen clones in Utah and Colorado indicates that seedlings were established many years ago (Barnes, in press). It is possible that some clones may have been initiated during Pliocene or Miocene times, enlarging themselves asexually through many generations of ramets.

Generally, when a clone of any plant is propagated vegetatively for a long period of time, it becomes infected with one or more viruses (Hartmann and Kester 1968). The clones degenerate with age because plants apparently never free themselves from virus infections (Bowden 1964). Once infected, a plant remains so for as long as it lives. Further, when vegetative parts of that plant are used for propagation, the progeny will also be infected in perpetuity.

This persistence of viruses means that vegetatively propagated plants probably are continually affected by all the viruses they have ever contracted. Of all pathogens, viruses are the most likely to cause the degeneration of clones with age, but systemic infection by fungi and bacteria might also be important. Considering the length of time aspen has reproduced vegetatively, it would be surprising not to find clones infected with viruses and other pathogens. Damage caused by these pathogens might intensify and spread in overmature ramets of low vigor.

In addition to its role in aspen regeneration, fire may also have controlled viruses and other pathogens in aspen clones. Periodic destruction of diseased plants by burning probably reduced the amount of inoculation and thus slowed the rate at which pathogens were transferred to a new crop of suckers. Removal of stems in logging may accomplish similar results.

LITERATURE CITED

lder, G. M.
1970. Age-profiles of aspen forests in Utah and northern Arizona. 31 p. M.S. Thesis, Univ. of Utah.

arnes, B. V.
1966. The clonal growth habit of American aspens. Ecology 47:439-447.

arnes, B. V.
1969. Natural variation and delineation of clones of *Populus tremuloides* and *P. grandidentata* in northern lower Michigan. Silvae Genet. 18:130-142.

arnes, B. V.
Phenotypic variation of trembling aspen of western North America. For. Sci. (in press).

owden, F. C.
1964. Plant viruses and virus diseases. 361 p. Ronald Press, N. Y.

opony, J. A., and B. V. Barnes.
1974. Clonal variation in the incidence of hypoxylon canker on trembling aspen. Can. J. Bot. 52:1475-1481.

liasson, L.
1971a. Growth regulators in *Populus tremula*. III. Variation of auxin and inhibitor level in relation to root sucker formation. Physiol. Plant. 25:263-267.

liasson L.
1971b. Growth regulators in *Populus tremula*. IV. Apical dominance and suckering in young plants. Physiol. Plant. 25:263-267.

very, A. D., and D. Weins.
1971. Triploidy in Utah aspen. Madroño 21(5):139-147.

armer, R. E.
1962. Aspen root sucker formation and apical dominance. For. Sci. 8:403-410.

ralish, J. S.
1972. Youth, maturity, and old age. *In*: Aspen: Symposium Proceedings. p. 52-58. USDA For. Serv. Gen. Tech. Rep. NC-1, North Central For. Exp. Stn., St. Paul, Minn.

raham, S. A., R. P. Harrison, Jr., and C. E. Westell, Jr.
1963. Aspens: phoenix trees of the Great Lakes Region. 272 p. Univ. Mich. Press, Ann Arbor, Mich.

ruell, G. E., and L. L. Loope.
1974. Relationships among aspen, fire, and ungulate browsing in Jackson Hole, Wyoming. 33 p. USDA For. Serv. & USDI Park Serv., U.S. Gov. Print. Off., Washington, D.C.

artmann, H. T., and D. E. Kester.
1968. Plant propagation, principles and practices. 702 p. Prentice-Hall, Inc., Englewood Cliffs, N. J.

Krebill, R. G.
1972. Mortality of aspen on the Gros Ventre elk winter range. USDA For. Serv. Res. Pap. INT-129, 16 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Loope, L. L., and G. E. Gruell
1973. The ecological role of fire in the Jackson Hole area, northwestern Wyoming. Quat. Res. 3:425-443.

Mielke, J. L.
1957. Aspen leaf blight in the Intermountain region. USDA For. Serv. Intermt. For. and Range Exp. Stn. Res. Note 42, 5 p. Ogden, Utah.

Schier, G. A.
1973a. Origin and development of aspen root suckers. Can. J. For. Res. 3:45-53.

Schier, G. A.
1973b. Seasonal variation in sucker production from excised roots of *Populus tremuloides* and the role of endogenous auxin. Can. J. For. Res. 3:459-461.

Schier, G. A.
1974. Vegetative propagation of aspen: clonal variation in suckering from root cuttings and in rooting of sucker cuttings. Can. J. For. Res. 4:565-567.

Schier, G. A.
Promotion of sucker development on *Populus tremuloides* root cuttings by an antiauxin. Can. J. For. Res. (in press).

Smith, A. D., P. A. Lucas, C. O. Baker, and G. W. Scotter.
1972. The effects of deer and domestic livestock on aspen regeneration in Utah. Utah Div. Wildl. Res. Publ. 72-1, 32 p.

Steneker, G. A.
1974. Factors affecting suckering of trembling aspen. For. Chron. 50:32-34.

Tew, R. K.
1967. Role of zinc, carbohydrate reserves, and soil properties in the vegetative reproduction of aspen. 108 p. Ph.D. Thesis, Utah State Univ., Logan.

Wall, R. F.
1971. Variation in decay in aspen stands as affected by their clonal growth pattern. Can. J. For. Res. 1:141-146.

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SCHIER, GEORGE A.

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Montana State University

University of Montana

AMERICAN REVOLUTION BICENTENNIAL

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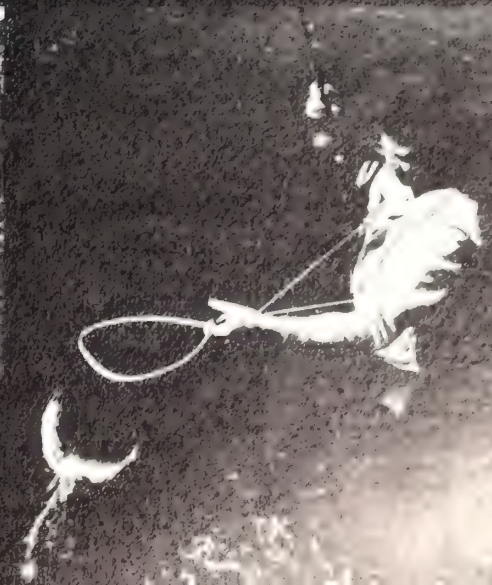
economic importance of tourism in montana



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ECONOMIC IMPORTANCE OF TOURISM IN MONTANA

Paul F. Polzin
Bureau of Business and Economic Research
University of Montana

and

Dennis L. Schweitzer
Intermountain Forest and Range Experiment Station

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401
Roger R. Bay, Director

THE AUTHORS

DR. PAUL E. POLZIN is a Research Associate in the Bureau of Business and Economic Research, University of Montana, and a Research Economist, Intermountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Missoula, Montana. He completed his graduate training in economics in 1968 at Michigan State University.

DR. DENNIS L. SCHWEITZER has been Principal Economist and Project Leader for Economics Research, Intermountain Station, at the Forestry Sciences Laboratory in Missoula, since 1972. Earlier he worked at the Pacific Northwest Forest and Range Experiment Station in Portland, Oregon, and the North Central Forest Experiment Station in St. Paul, Minnesota. He completed his graduate training in forest economics in 1968 at the University of Minnesota.

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ABSTRACT

About one-fourth of each tourist dollar accrues to Montanans as income; the proportion is smaller for expenditures by outdoor recreationists. It is unlikely that growth in tourism could offset income losses resulting from even moderate declines in timber harvesting. Tourist and timber industry employment differ in many respects.

INTRODUCTION

Montana's natural beauty and opportunities for outdoor recreation annually bring
any thousands of visitors to the State. The Highway Department estimates that during
971 approximately 3,770,000 out-of-State tourists spent, on the average, about $40 per
sit within the State. Total expenditures exceeded $150 million.

The number of visitors and their spending have often been cited to demonstrate the
nportance of tourism to Montana's economy. We feel these figures must be tempered with
ne recognition that only a fraction of tourist dollars directly accrues to Montanans.
ourist dollars are spent mainly on items such as food, equipment, and curios, most of
hich are not produced in Montana. Consequently, a significant portion of merchants'
eceipts quickly leave the State in payment for imported goods.

To put tourism in its proper perspective in this paper, we estimate the number of
ourist dollars that actually find their way into the pockets of Montanans. Because
the extensive opportunities for outdoor recreation in the State, we separately ex-
mine the economic contributions of those tourists who are campers, hunters, and
shermen.

Outdoor recreation and timber harvesting are sometimes viewed as competing uses
forest lands. After comparing the incomes derived by Montanans and other character-
tics of these two industries, we show that trade-offs in employment would bring
nsequences that are neither simple nor obvious.

MONTANA INCOME FROM TOURISTS

The economic importance of tourism to Montana depends not only on the number of tourists and the number of dollars they spend, but also on how they spend their money We first examine how nonresident visitors distribute their expenditures among purchas of lodging, food, transportation, and all other items. (Because such information is severely limited for Montana, we draw heavily on studies conducted in other States.) After developing benchmark estimates for the "average" Montana tourist, similar esti- mates are made for three subgroups--campers, hunters, and fishermen--whose spending patterns might be expected to differ. These figures are then used to estimate the pr portion of tourist expenditures that accrue to Montanans as direct income.

How Tourists Spend Money

The "Average" Tourist

A 1964 survey of outbound nonresident motorists indicated that 28 percent had Montana as their primary destination; the remainder were simply passing through the State (Wallace and Blake 1966, p. 84). Of the nonresidents staying at Montana lodgin facilities, 52 percent were there for pleasure and the remainder were on business or some combination of business and pleasure. These are average figures for the entire year; during the summer, the proportion visiting for pleasure or to see relatives and friends rose to 73 percent. The average distribution of the expenditures of all non- resident visitors in that year is summarized in table 1.

Table 1.--*Distribution of expenditures of the "average" tourist in Montana, 1964*

Category	Proportion of expenditures
	Percent
Lodging	27
Food	33
Transportation	26
All other	14
Total	100

Source: Wallace and Blake (1966, p. 94).

Campers

The distributions of expenditures by nonresident campers in several States are summarized in table 2. The Montana data reflect dollars spent by those tourists who chose to stay in established campgrounds in 1964. At that time, camping fees were much less common than today. The more recent studies in Arizona and Georgia led us to adjust these 10-year-old estimates as indicated.

Is our adjustment reasonable? This question has to be answered on two levels. Our estimate is intuitively reasonable in that lodging remains a relatively small proportion of all expenditures by campers and is in general agreement with the estimates from other sources. Perhaps more importantly, our later estimate of the returns to Montanans from camper expenditures is relatively insensitive to the breakdown chosen. We estimate later that about $0.17 of the camper-dollar ends up as direct income; the 1966 Montana data yield $0.17 and the Georgia data $0.18. For every grouping of tourists, our later estimates of direct Montana income per dollar spent are within 1 cent of the values that would be obtained by using averages of the cited studies.

Table 2.--*Distribution of expenditures by nonresident campers*

Category	In published studies			Estimated for Montana in this study
	Montana	Georgia	Arizona[2]	
	Percent			
Lodging[1]	3	11	Unknown	10
Food	50	29	36	35
Transportation	32	36	44	38
All other	15	24	Unknown	17
Total	100	100		100

[1] Includes camping and admission fees.
[2] Lodging and all other expenditures could not be derived from study.

Sources: Montana--Wallace and Blake (1966, p. 90).
Georgia--Keeling and Hein (1970, p. 23).
Arizona--Leaming and others (1970, p. 108).

Fishermen

Because there are no data available on how nonresident fishermen in Montana spend their money, we have estimated their spending patterns from published studies in Colorado, Arizona, and Wisconsin (table 3). Perhaps because of differences in defining expenditure categories, conflicting results appear among the studies; for example, the Colorado survey reports that a large share of expenditures by fishermen were for lodging. Discrepancies also occur in the "Transportation" and "All other" categories. Probably because more than 4-out-of-5 of the respondents were from neighboring Illinois or Minnesota, the Wisconsin study showed a far smaller proportion was spent for transportation (Fine and Werner 1960, p. 2) than the other studies. As a consequence, a larger percentage was left over for "All other" expenditures.

For Montana we assume that nonresident fishermen allocate 22 percent of their spending (excluding licenses) to lodging, which is somewhat less than the average tourist. We estimate $0.23 of every dollar is spent in the "All other" category--mostly, fishing equipment and supplies--which all three studies reported to be significant.

Table 3.--*Distribution of expenditures by nonresident fishermen (Excludes license fees)*

Category	In published studies			Estimated for Montana in this study
	Colorado	Arizona	Wisconsin	
	Percent			
Lodging	33	18	22	22
Food	23	23	24	23
Transportation	29	34	12	30
Guides	2	1	2	2
All other	13	24	40	23
Total	100	100	100	100

Sources: Colorado--Rohdy and Lovegrove (1970, table 2).
Arizona--Davis (1967).
Wisconsin--Fine and Werner (1960, p. 4).

Correspondingly, the values for food and transportation are assumed to be below those of average tourists; food constitutes 23 percent of total spending, transportation 30 percent. Finally, a fifth expenditure category--fishing guides--has been added for this analysis. Guide services can vary from showing clients where and how to fish to also providing lodging, food, and tackle. The studies report that payments to guides represent only a small portion of total spending by fishermen; we assume that only 2 percent is so spent in Montana.

The three studies cited in table 3 derive their data from samples of nonresident fishing licenses. They do not distinguish between those whose primary purpose was fishing and others who fished as a sidelight to their visit. Thus, to the extent these samples contain the occasional fishermen, they may not accurately represent those attracted by quality outdoor fishing. Approximately one-third of all summer visitors in Montana bought fishing licenses (Wallace and Blake 1966, p. 70).

Hunters

As with fishermen, no comprehensive studies of hunter expenditures have been prepared for Montana. Again we will rely on data for other States as a guide to estimating appropriate values for Montana.

The distribution of expenditures for nonresident big game hunters in Colorado and Arizona are summarized in table 4. These surveys differ only in the "All other" and "Guide" categories. These differences appear to be definitional or due to the way we recombined categories for our tabular presentation; in both instances, the sum of these two categories is about the same proportion of total expenditures.

In Montana we assume lodging accounts for 13 percent of total expenditures (excluding licenses), which reflects the tendency of hunters to camp, use cabins, or even sleep in their cars (Davis 1967, p. 35). Both the Colorado and Arizona studies report significant expenditures for equipment and supplies. Consequently, the "All other" category is estimated to account for about 30 percent of expenditures. A Montana law requires nonresident big game hunters in certain areas to be accompanied by a licensed resident--often a guide or outfitter. Thus, 10 percent for the "Guide" category does not seem unreasonable. The relative importance of the "Food" and "Transportation" categories will be assumed to be 22 and 25 percent, respectively--a lower proportion than for the average tourist due to the upward adjustments in the other categories.

Table 4.--*Distributions of expenditures by nonresident big game hunters (Excludes license fees)*

Category	In published studies		Estimated for Montana in this study
	Colorado	Arizona	
	Percent		
Lodging	12	14	13
Food	23	18	22
Transportation	26	28	25
Guides	13	3	10
All other	26	37	30
Total	100	100	100

Sources: Colorado--Rohdy and Lovegrove (1970, table 1).
Arizona--Davis (1967, p. 34).

Direct Income Per Dollar Spent

Only a portion of the dollars spent by tourists ends up in the pockets of Montanans and the size of that portion depends on how the dollars are spent. Table 5 shows 1967 receipts and earnings for selected industries that cater to tourists. These data show that in-State earnings per dollar of receipts vary significantly among industries: for each dollar spent in hotels, $0.39 is retained by Montanans as personal earnings, but for each dollar spent in food stores only $0.10 goes into the pockets of residents. Although the data were taken in 1967, we do not believe the ratios of earnings to receipts have changed. These ratios show the portion of tourist dollars that accrues to Montanans as direct income in the form of employees' wages and salaries and proprietors' income of those owning the businesses. Because the ratios do not reflect certain payments to local utilities or manufacturers, portions of which do accrue to Montanans, the ratios underestimate income retained in the State.

Given the earnings-to-receipts ratios and the distributions of spending, we can determine the share of tourist expenditures that accrue to Montanans.

The "Average" Tourist

The distribution of the expenditures of the "average" tourist was summarized in table 1. Of those utilizing commercial accommodations, approximately two-thirds stayed in motels; most of the others utilized hotels or campgrounds (Wallace and Blake 1966, p. 60). So we estimate the earnings per dollar of receipts for lodging from "average" tourists was $0.25, slightly above the ratio of $0.21 reported for motels and far smaller than the ratio of $0.39 for hotels in table 5.

The earnings per dollar of receipts in the "Food" category is assumed to be $0.25, because the information available suggests that out-of-State visitors spent about 90 percent of their food money in restaurants.

We also know that about 15 percent of the nonresidents staying in Montana overnight did not arrive by automobile (Wallace and Blake 1966, p. 24). Unfortunately, data on income to Montanans from tourists' transportation expenditures are available only for sales of automobile-related goods and services. We simply do not know the earnings-receipts ratio for expenditures on bus, train, or airplane travel. We estimate that the Montana earnings per dollar of receipts for all transportation

Table 5.--*Receipts and earnings in selected Montana industries, 1967*

Industry category	Receipts	Earnings, including proprietors'[1]	Earnings, per $ of receipts
	Thousands		
Lodging			
Hotels (SIC 7011)	$ 14,862	$ 5,813	0.39
Motels (SIC 7011)	14,914	3,175	.21
Trailer Parks (SIC 7031)	1,154	101	.09
Sporting and Recreational camps (SIC 7032)	1,440	394	.27
Food			
Eating and Drinking places (SIC 58)	95,694	25,391	.27
Foodstores (SIC 54)	247,524	24,829	.10
Transportation			
Auto Repairs (SIC 753)	13,180	3,879	.29
Gas Stations (SIC 554)	101,594	11,601	.11
Other			
Merchandise:			
General Merchandise (SIC 53)	104,936	18,869	.18
Apparel and Accessories (SIC 56)	47,311	7,821	.17
Sporting Goods (SIC 595)	5,882	866	.15
Amusements			
Motion Pictures (SIC 78)	4,810	1,579	.33
Amusements (SIC 79)	7,555	2,341	.31

[1] Proprietors' earnings estimated from U.S. Department of Commerce, Regional Economics Information System, Washington, D.C., unpublished data.

Sources: U. S. Bureau of the Census, Census of Business, 1967, Selected Services; Montana BC 67-SA28, U.S. Government Printing Office, Washington, D.C., 1969, table 2.

U.S. Bureau of the Census, Census of Business, 1967, Retail Trade; Montana, BC67-RA28 U.S. Government Printing Office, Washington, D.C. 1969, table 2.

SIC = Standard Industrial Classification

expenditures is $0.15--again referring to table 1 and reasoning that most spending is for gasoline rather than auto repairs and that commercial transportation does not significantly change this value.

The Montana study also suggests that other expenditures were about evenly divided between recreation and merchandise. The earnings-receipts ratio in the "All other" category is estimated to be $0.23--the approximate midpoint between the values for merchandise and amusements in table 5.

Given these local earnings per dollar of tourist expenditures and the distribution of expenditures shown in table 1, the Montana direct income from each dollar spent by "average" tourists can be calculated from the following:

[Montana earnings]
[from "average" tourist dollar] =

[(Proportion spent for lodging) × (Earnings per dollar for lodging)]
+ [(Proportion spent for food) × (Earnings per dollar for food)]
+ [(Proportion spent for transportation) × (Earnings per dollar for transportation)]
+ [(Proportion spent for all other) × (Earnings per dollar for all other)]

$0.2212 = [(0.27) × ($0.25)] + [(0.33) × ($0.25)]
+ [(0.26) × ($0.15)] + [(0.14) × ($0.23)]

We conclude, then, that the average dollar spent by tourists yields $0.22 in direct wages and income for Montanans.

We emphasize that these calculations provide only a rough estimate of the impact of an average tourist dollar. Much of the data is out of date or incomplete. A number of key values are "guesstimates." Our chief purposes are to demonstrate a methodology and to provide an "average tourist" norm that can be compared with similar estimates for subgroups of tourists who camped, fished, or hunted in the State.

Campers

Earnings per dollar of lodging receipts is assumed to be $0.25, which is roughly halfway between the values for motels and recreational camps reported in table 5, because most campers occasionally stay in a motel or hotel. Wallace and Blake, (1966, p. 90) reported that approximately 40 percent of the camper's food dollar was spent in restaurants. Consequently, the value for grocery stores shown in table 5 was given a greater relative weight, and the earnings per dollar of receipts for food was assumed to be $0.17--considerably lower than for the average tourist. The ratio of earnings to receipts in the "Transportation" category remains unchanged at $0.15. Because both the Montana and Georgia studies suggest that campers spend considerably more for merchandise than for amusements, the earnings-receipts ratio in the "All other" category was reduced to $0.19, down from the $0.23 used for average tourists.

Table 6.--*Montana direct income per dollar spent by out-of-State recreationists*

Type of recreationist	Montana income per dollar spent		Lodging: Proportion spent	Lodging: Earnings per $ of receipts		Food: Proportion spent	Food: Earnings per $ of receipts		Transportation: Proportion spent	Transportation: Earnings per $ of receipts		Guides: Proportion spent	Guides: Earnings per $ of receipts		All other: Proportion spent	All other: Earnings per $ of receipts
Average tourists	$0.2212	=	(0.27	× $0.25)	+	(0.33	× $0.25)	+	(0.26	× $0.15)	+	(0)	+	(0.14	× $0.23)
		=	$0.0675		+	$0.0825		+	$0.0390		+	0	+	$0.0322		
Campers	.1738	=	(0.10	× $0.25)	+	(0.35	× $0.17)	+	(0.38	× $0.15)	+	(0)	+	(0.17	× $0.19)
		=	$0.0250		+	$0.0595		+	$0.0570		+	0	+	$0.0323		
Fishermen	.2000	=	(0.22	× $0.25)	+	(0.23	× $0.22)	+	(0.30	× $0.15)	+	(0.02	× $0.40)	+	(0.23	× $0.18)
		=	$0.0550		+	$0.0506		+	$0.0450		+	$0.0080		+	$0.0414	
Hunters	.2058	=	(0.13	× $0.25)	+	(0.22	× $0.19)	+	(0.25	× $0.15)	+	(0.10	× $0.40)	+	(0.30	× $0.18)
		=	$0.0325		+	$0.0418		+	$0.0375		+	$0.0400		+	$0.0540	

To calculate Montana's income from tourists staying in established campgrounds, we follow the procedure used for "average" tourists. These calculations are summarized in table 6 for all classes of tourists. For each dollar spent by campers, about $0.17 is retained by Montanans, almost one-fourth less than for all visitors. This difference is due to campers spending a greater proportion in categories with low earnings-receipts ratios, such as transportation, and the lower earnings per dollar of receipts in the "Food" and "All other" categories.

Fishermen

The Arizona and Wisconsin studies report that, of those fishermen using commercial accommodations, most stayed in motels (Davis 1967, p. 30; Fine and Werner 1960, p. 3). An earnings-receipt ratio of $0.25, the same as for the average tourist, will be used for the "Lodging" category. The Wisconsin study also reports that fishermen spent almost twice as much in grocery stores as in restaurants (Fine and Werner 1969, p. 4). We assign an earnings-receipts ratio for food of $0.22 in light of the lower Montana earnings ratio for grocery stores shown in table 5. In the absence of contradictory information, we again assume that each dollar spent for transportation will provide $0.15 of direct income. The value for all other expenditures will be assumed to be $0.18, based on our reasoning that very little was spent by fishermen for amusements as defined in table 5. Finally, the earnings per dollar of receipts for guides is set at $0.40. There are no hard data to support this assertion, but one would expect these activities to be relatively labor intensive and to have high earnings-receipts ratios.

Based on these assumptions, and the distribution of expenditures shown in table 3, the Montana income per dollar of nonresident fishermen expenditure is estimated to be $0.20, as calculated in table 6.

Hunters

With the exception of food, earnings-receipts ratios for hunters are the same as for fishermen. We think $0.19 of each dollar spent by hunters for food ends up as direct income because they probably spend more in grocery stores than in restaurants. The last lines in table 6 show that the average dollar spent by nonresident big game hunters generates about $0.21 in direct income to Montanans.

Recapitulation of Direct Income Per Tourist Dollar

The previous sections examined the direct economic impacts of dollars spent by four classes of out-of-State visitors to Montana. The analytical method used the findings of studies for other States in order to circumvent some of the data deficiencies for Montana, but a good deal of informed judgment was also required. Based on our best estimates the direct incomes generated by each dollar spent by tourists are about:

"Average" tourists	--	$0.22 per dollar spent
Campers	--	.17 per dollar spent
Fishermen	--	.20 per dollar spent
Hunters	--	.21 per dollar spent

The components of these receipts are pictured in figure 1.

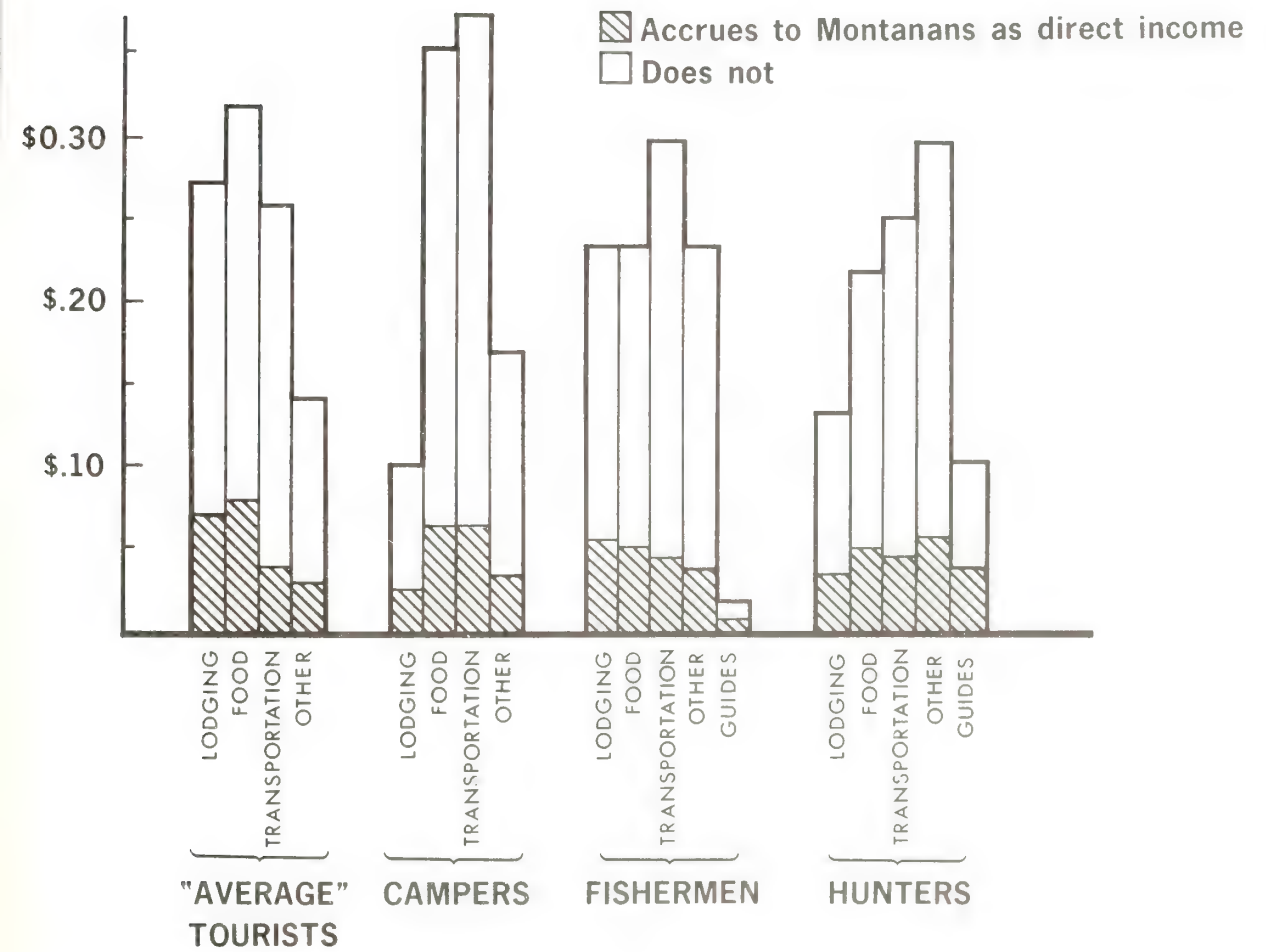

Figure 1.--The way out-of-State tourists spend their dollars in Montana.

Although these numbers should not be taken too seriously, we believe that the overall ranking is accurate; the Montana income per dollar of expenditure is lower for out-of-State outdoor recreationists than for the more inclusive category of out-of-State tourists. Campers, fishermen, and hunters spend a smaller percentage of their dollars on the categories with high earnings-receipts ratios, such as motels, restaurants, and amusements, and spend relatively more on transportation, groceries, and merchandise that brings low earnings per dollar of receipts. Or, stated in a different way, the economic advantage to Montanans of expenditures by outdoor recreationists, on a per-dollar-spent basis, is less than for "average" motel- and restaurant-dependent tourists.

Total Direct Income From Tourists' Expenditures

The State Highway Commission of Montana (in unpublished data) has made estimates of total visitor expenditures by updating certain findings of the 1966 Montana Travel Study. The Commission estimates that during 1971 there were approximately 3,770,000 out-of-State visitors who spent, on the average, about $40 per visit. Total expenditures, then, were roughly $150 million.

Earlier we estimated that about $0.22 of each dollar spent by the "average" tourist became direct income to Montanans. Applied to the above estimate of total expenditures, "average" tourists accounted for $33 million in direct wages, salaries, and proprietory incomes. These figures and estimates of expenditures by out-of-State outdoor-oriented recreationists are summarized in table 7. Recall that the recreationists' expenditures are included in those of the "average" tourists.

The Montana and Georgia studies suggest that the average expenditure by campers may be about 60 percent of the expenditures of the average tourist. Neither study indicates a significant difference in the length of stay between campers and all tourists (although camping parties appear to be somewhat larger than average). Therefore, $24.00 (= 0.60 × $40.00) is estimated to be the average expenditure per camper per visit.

Table 7.--*Individual and total tourist contributions to direct income of Montanans, 1971*

Type of visitor	Direct income per dollar spent	Average expenditure per visitor	Direct income per visitor	Number of visitors	Total Expenditure	Total direct income[1]
Average tourists[2]	$0.22	$40.00	$ 8.80	3,770,000	$150,800,000	$33,176,000
Hunter	.21	78.00	16.38	12,000	[3]936,000	197,000
Fishermen	.20	58.00	11.60	32,500	[3]1,885,000	377,000
Camper	.17	24.00	4.08	400,000	9,600,000	1,632,000

[1] Wages, salaries, and proprietorial income to Montanans.
[2] Hunters, fishermen, and campers are included in the figures for "average" tourists.
[3] Excludes license fees.

The Montana Travel Study (Wallace and Blake 1966, p. 28) estimated that about 11 percent of the nonresident tourists in 1964 used campgrounds. (Wallace and Blake did not cover those who camped outside established campgrounds, and neither do we.) If this proportion held in 1971, more than 400,000 campers spent about $9,600,000, with direct income to Montanans of about $1,600,000.

Only fragmentary, unpublished data are available on spending by nonresident fishermen and hunters. From such information we speculate that fishermen spent half again as much as average tourists, or about $58.00 per visit, and hunters twice as much, perhaps $78.00 per visit (both figures exclusive of license fees).

The Montana Fish and Game Commission has reported that of the 177,500 nonresident fishing licenses sold in 1971-72, 145,000 were for only 1 day. We believe these sales were to "casual" fishermen having other major business in the State. This leaves approximately 32,500 "serious" nonresident fishermen who purchased either 6-day or season licenses. We use the 12,000 big game hunting licenses sold as our estimate of the number of nonresident hunters.

From these figures we estimate the following contributions in direct income by out-of-State sportsmen: hunters, $197,000; fishermen, $377,000.

COMPARISONS OF THE TOURIST AND WOOD PRODUCTS INDUSTRIES

With the information we have developed for the tourist industry and comparable, published data for the forest products industries, we can compare the economic importance of tourism and timber production within Montana. We compare the direct income generated by each, their total economic importance, and finally the characteristics of employment in the two industries.

Comparison of Direct Income

The relationship between timber harvested and the numbers of jobs generated depends on many factors. An increase in the harvest may have one effect if it occurs during an economic slump when there are many unemployed Montanans who could be put to work and quite a different effect if it occurs during a boom period. Recognizing these difficulties, Johnson (1972) and Polzin (1973) have estimated that a million-board-foot change in Montana's timber harvest is associated with a change of approximately five jobs in the wood products industry and approximately $37,500 in personal earnings, that is, a change of 1 million board feet of timber harvesting will lead to a change of $37,500 in direct income to Montanans.[1]

Given the data in table 7, we can calculate the number of nonresident visitors required to match the direct income of the wood products industry. For example, we know the "average" tourist generates $8.80 of direct income. Then,

[Number of average tourists necessary to generate $37,500 of direct income] $= \frac{(\$37,500)}{\$8.80}$

$=$ 4,260 "average" tourists.

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[1] This suggests that the marginal wood products worker earns $7,500 per year (= $37,500 ÷ 5), slightly less than the $8,300 average annual earnings of all wood products employees. In contrast, we see no reason to believe a marginal tourist would spend any more or less than the "average" tourist. To be consistent with our analysis of the tourist industry, we have excluded any payments by the wood products industry for items such as local taxes and utilities.

Table 8.--*Some relationships among direct incomes to Montanans generated by nonresident visitors and by timber*

Type of visitors	Expenditures generating same direct income as 1 million board feet of timber	Visitors generating same direct income as 1 million board feet of timber[1]		Number of board feet of timber generating same direct income as 1971 total number of visitors[2]
		Number	Number as percent of 1971 visitors	
Average tourists[3]	$170,000	4,260	0.1	885 million
Hunters	178,000	2,290	19.1	5 million
Fishermen	188,000	3,230	9.9	10 million
Campers	221,000	9,190	2.3	44 million

[1] Based on average expenditures and numbers of visitors reported in table 7.
[2] Total annual timber harvest in Montana during 1971 was about 1,300 million board feet.
[3] Hunters, fishermen, and campers are included in the figures for "average" tourists.

To find the total expenditures necessary to generate this direct income, we can either divide $37,500 by $0.22 (the direct income per dollar spent) or we can multiply 4,260 tourists by $40.00 (average total expenditure). In either case we learn that roughly 4,260 "average" tourists must spend about $170,000 to generate the same direct income as that resulting from the harvesting and processing of a million board feet of timber. Comparable values have been calculated for the subgroups of nonresident hunters, fishermen, and campers and are displayed in table 8.

Policymakers inclined to develop the recreation economy to offset a possible decline in the harvest of timber would find their greatest opportunities in promoting general tourism rather than concentrating on hunting and fishing. A disproportionate increase in hunters and fishermen would be required to make any appreciable difference to Montanans.

Total Contributions to Personal Income

As direct income to Montanans is spent and respent within the State, it multiplies. Johnson (1972) estimates that the income multiplier for Montana is 3.09; total personal income will change by $3.09 for each $1.00 change in direct income.

Earlier we estimated that all tourism created $33 million in direct income to Montanans; eventually, this figure is multiplied to about $102 million. The Regional Economic Information System reports that direct income in the private wood products industry (excluding the Forest Service and other government agencies) was approximately $81 million in 1971. Income multiplication suggests that timber harvesting accounted for about $250 million in total personal income in Montana.

The U.S. Department of Commerce reports that total personal income in Montana was $2,627 million in 1971. Thus, the $102 million created directly and indirectly by tourists represents slightly less than 4 percent of the total. Timber harvesting accounted for about 9.5 percent of total personal income in the State in that year.

We do not believe that tourists and timber are good substitutes for one another. The industries are quite dissimilar; they employ different kinds of workers, pay different wages, and buy from different suppliers. A change in one of these industries even if compensated by an appropriate increase or decrease in the other, would have repercussions throughout the State. In the following sections we outline some of the differences between the wood products and tourist industries by examining their interrelationships with other Montana industries and their employment and earnings characteristics.

Linkages to Other Industries

The tourist and wood products industries use different goods bought from different suppliers. Therefore, a switch from wood products to tourism (or vice versa), may bring economic repercussions beyond those measured in terms of direct income and employment characteristics.

The relationships between suppliers and buyers, often called "linkages," are best analyzed using input-output techniques. Although the input-output model (Mitchell 1971) available for Montana is not well suited for our approach, it can shed some light on the different interindustry linkages of the tourist and wood products industries.

Table 9 presents the distribution of expenditures by wood products, wholesale and retail trade, and service industries. (Figures for the trade and service industries are not comparable to those presented earlier. Figures in table 9 include many more firms than just those oriented toward tourists, and the expenditures by the wholesale

Table 9.--*Distribution of the average dollar spent by selected Montana industries*

Selling industries	Purchasing industries			
	Logging	Wood processing	Wholesale and retail trade[1]	Services[2]
1. Logging	$0.11	$0.14		
2. Wood processing		.03		
3. Other manufacturing	.02	.01	$0.02	
4. Transportation	.10	.17	.07	
5. Communications and public utilities	.01	.03	.06	$0.01
6. Construction		.03	.01	
7. Agriculture and mining		.01		
8. Wholesale and retail trade	.04	.05	.03	.02
9. Services[2]	.02	.03	.06	.04
10. Households	.50	.32	.61	.65
11. State and local governments	.01	.06	.05	.01
12. Federal government	.10	.02	.05	.03
13. Out-of-State	.09	.10	.04	.24
Total	$1.00	$1.00	$1.00	$1.00

[1] Excludes purchases of goods sold.
[2] Including finance, insurance, and real estate.

and retail trade industries do not include the costs of goods sold.) Reading down the columns of the table shows how the average dollar was spent. For example, logging firms spent $0.10 for services purchased from transportation firms (row 4). Missing entries reflect small or no purchases.

We see that logging and wood processing firms buy heavily from other wood products firms and the transportation industry. The largest entries for wholesale and retail trade, excluding wages and salaries paid to households, are for transportation, communications and public utilities, and services. Many of the figures for the service industry are zero or very small, indicating that they buy little from other firms. This is to be expected because the service industry, as defined in the available input-output analysis, includes many firms whose primary output consists of services provided by people. This is reflected in the large purchases from "households," which include wages and salaries.

The interindustry linkages shown in table 9 imply that different suppliers would be affected by changes in the wood products and tourist industries. For example, the relative impact on transportation would be greater for an increase in wood products than for tourism. Conversely, communications and public utilities would benefit more from growth in trade and the services.

Earnings and Employment

The low pay of tourist-oriented jobs has been mentioned by others (Johnson 1968). Average annual earnings for the wood products and other selected industries confirm these findings (table 10). For a more detailed examination of employment in Montana's wood products industry, see Porterfield (in press). During 1971, workers in wood products averaged $8,300 in earnings. None of the industries that serve out-of-State tourists even comes close to this figure. In fact, workers in lodging and eating and drinking places, establishments most closely associated with tourist spending, average less than one-half that amount. Employees in foodstores and amusement places fare better, but jobs associated with the harvesting and processing of timber still pay higher wages than those oriented toward tourism.

Table 10.--*Average annual earnings of employees in selected industries, Montana, 1971*

Industry	Average annual wages and salaries
Wood products (SIC 24+25+26+08)	$8,300
Hotels, motels, and lodging places (SIC 70)	3,300
Eating and drinking places (SIC 58)	3,200
Foodstores (SIC 54)	5,400
Amusements (except motion pictures) (SIC 79)	3,600

Sources: U.S. Department of Commerce, Regional Economics Information System, unpublished data, 1974. (Supplied through Montana Department of Intergovernmental Services.)
SIC = Standard Industrial Classification.

Table 11.--*Proportion of employees in selected Montana industries by sex and number of weeks worked, 1970*

Industry	Male employees	Number of weeks worked		
		50-52	27-49	1-26
	Percent			
Wood products[1]	96	63	29	8
Foodstores	54	67	17	16
Gasoline service stations	91	65	18	17
Eating and drinking places	30	44	25	31
General merchandise stores	29	60	21	19
Hotels and lodging places	30	52	22	26

[1] Includes logging, sawmills, planing mills, and millwork, miscellaneous wood products, furniture and fixtures, and paper and allied products.

Sources: U.S. Bureau of the Census, Census of Population: 1970, Detailed Characteristics, Final Report PC (1-D28), Montana, U.S. Government Printing Office, Washington, D.C., 1972, tables 185 and 186.

Most jobs in wood products are filled by males. Tourist-oriented industries employ mostly females, which accounts for at least a portion of the inequality in earnings. Table 11 reports that 96 percent of the workers in wood products are male. Among industries catering to tourists, only gasoline service stations, with about 91 percent male, approach this figure. In lodging places and restaurants, 70 percent of employees are women.

The regularity of employment also favors the wood products workers. Table 11 shows that during 1969 about 63 percent of the experienced labor force employed in wood products worked 50-52 weeks. Of those remaining, 29 percent worked 27-49 weeks and 8 percent worked less than 26 weeks. Among tourist industries, foodstores and gasoline service stations had a slightly higher proportion working year-round. However, they also had a greater share working less than half of the year. Year-round employees constitute even a smaller share of the total in the other industries that cater, at least in part, to out-of-State tourists.

Both the wood products and tourist industries are distinctly seasonal, as illustrated in Figure 2. Although this seasonality of employment varies somewhat from year to year in response to economic conditions, it appears to be consistently greater for the tourist industry.

In addition to working fewer weeks per year, there is some evidence that employees in tourist-oriented industries also work fewer hours per week. The Montana Department of Labor and Industry reports that during 1971 workers in manufacturing (which includes wood products) averaged 39.8 hours per week. The average weekly hours for wholesale and retail trade workers was 36.0 and for services the average was 34.6 hours. (See Montana Department of Labor and Industry, *Montana Employment and Work Force Supplements*, 1971-72, Helena, 1973, Suppl. II, p. 37.)

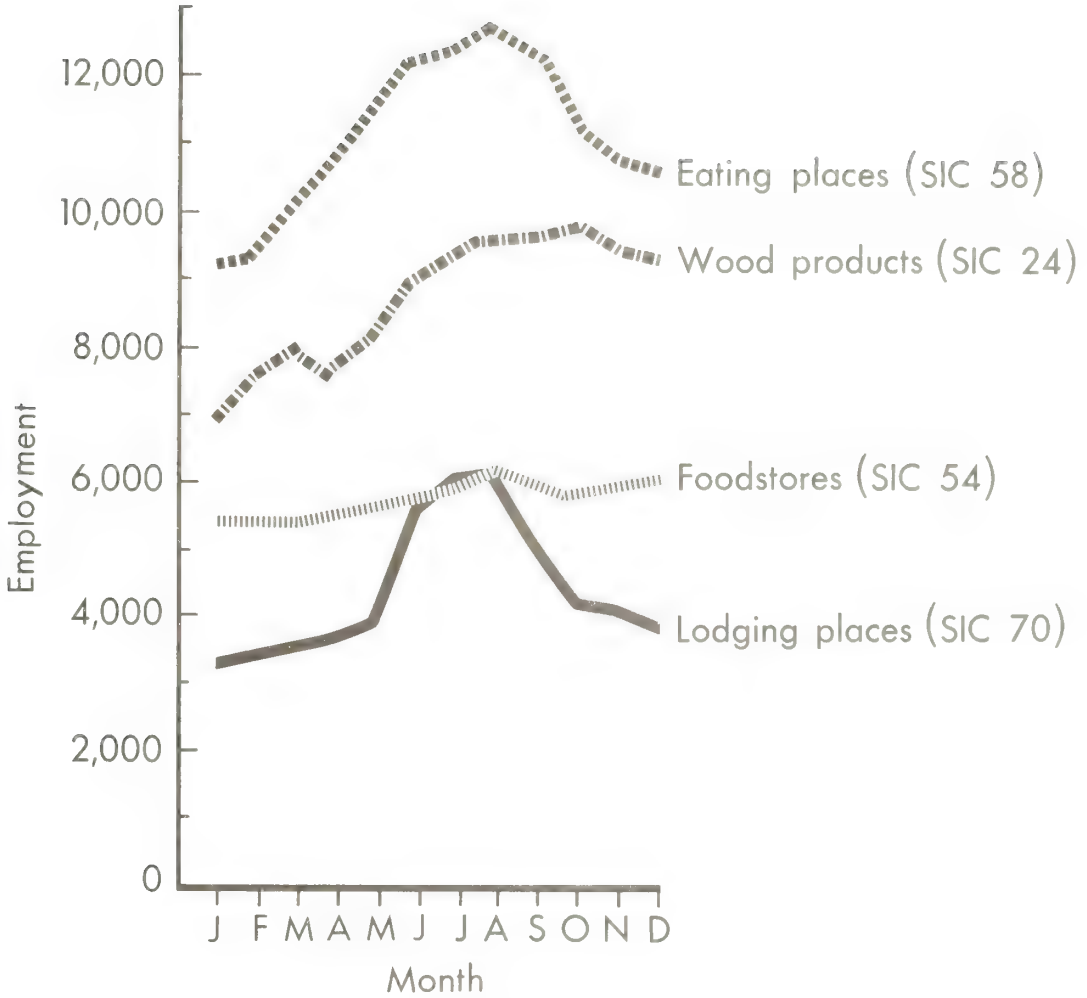

Figure 2.—Monthly employment in the Montana tourist and timber industries, 1971. (SIC = Standard Industrial Classification.) Source: Montana Department of Labor and Industry, "Employees of Montana Nonagricultural Payrolls, 1971," Suppl. 1, Helena. 1973.

In light of these findings, we could describe the average wood products employee as male, earning about $8,300 in wages and salaries, and working for most of the year (but with some seasonal layoffs). In contrast, the typical employee serving tourists is more likely to be female, earn about one-half to two-thirds of that salary and work for fewer weeks per year. These characteristics do not make tourist jobs inherently undesirable; in fact, they may be very desirable for working wives, students, or others. But the differences between the industries suggest that a shift from one to the other would be accompanied by significant changes in Montana's labor market. Jobs created in one sector might not match the needs, desires, or qualifications of the unemployed. Simply matching job decreases with corresponding increases in other industries does not tell the whole story, for one job may be full time and relatively high paying while the other is seasonal with low wages.

A FINAL WORD

Simply looking at total expenditures of tourists dramatically overestimates the number of dollars which end up in the pockets of Montanans. Based on the data presented here, we believe that between $0.20 and $0.25 of the average tourist dollar becomes direct income to residents of the State. Further, spending patterns suggest that dollars spent by motel- and restaurant-dependent tourists contribute more to the direct income of Montanans than do equal numbers of dollars spent by outdoor-oriented tourists such as campers, hunters, and fishermen.

Timber harvesting and tourism have been viewed by some as competing uses of Montana's resources. We calculated the number of tourists needed to offset the economic consequences to Montanans of reducing the timber harvest. In each case we examined, a very large increase in tourism would be required. Thus, we conclude that, for all practical purposes, the State could not generate sufficient growth in tourism to counter-balance even moderate declines in timber harvesting.

This is not to say that tourism and recreation cannot be of immense economic value. If sufficient expenditures can be stimulated, many local economies may be strengthened (Beardsley 1971). However, such strengthening is an extremely difficult task. It would be most desirable to try to develop tourism as a complement to, not a substitute for, timber production.

Further examination of the tourist and wood products industries revealed that simply trading timber harvesting for increased tourism, even if successful in generating equivalent spending, may prove unsatisfactory. There are simply too many less-than-obvious differences in secondary economic consequences and the nature of the jobs in the two industries.

In this study we have looked at the tourist and timber industries from the point of view of residents of Montana. Although important, this perspective is not a sufficient basis for policy formulation. In terms of the National Environmental Policy Act, we have concentrated on a regional economy without paying similar attention to the national economy. The distinction is especially important in Montana where more than 80 percent of the forested land base is in Federal ownership. To make judgments about what should be done without examining alternatives from the national viewpoint--without defining the economic implications of the tourist and timber industries to the nation as a whole--would be shortsighted. In this paper we have just taken one step in developing information that might be used to determine how Montana's forest resources might best serve the State and the Nation.

PUBLICATIONS CITED

Beardsley, Wendell G.
1971. The economic impact of recreation development: a synopsis. *In* Recreation Symp. Proc., p. 28-32. Northeastern For. Exp. Stn., USDA For. Serv., Upper Darby, Pa.

Davis, William C.
1967. Values for hunting and fishing in Arizona, 1965. Coll. Bus. and Public Adm., Univ. Ariz., Tucson.

Fine, I. V. and E. E. Werner.
1960. Economic significance of fishing in Wisconsin. Bur. Bus. Res. and Serv., Univ. Wisc., Madison.

Johnson, Maxine C.
1968. The tourist industry: some second thoughts. Mont. Bus. Q., p. 20-26, Bur. Bus. Econ. Res., Univ. Mont., Missoula.

Johnson, Maxine C.
1972. Wood products in Montana. Mont. Bus. Q. 10(2). Bur. Bus. Econ. Res., Univ. Mont., Missoula.

Keeling, William B. and Polly W. Hein.
1970. Characteristics of out-of-State campers. Div. Res., Univ. Georgia, Athens.

Leaming, George F., James M. Broer, Nat de Gennaro, and Marley Jannagen.
1970. The economic impact of the Oryon Pipe Cactus National Monument. Div. Econ. and Bus. Res., Univ. Ariz., Tucson.

Mitchel, Donald O.
1971. An updated input-output study of Montana. M.S. Thesis, Mont. State Univ., Bozeman.

Polzin, Paul E.
1973. Economic impact of proposed timber management guidelines, Reg. 1, U.S. For. Serv. Reg. Off., Missoula, Mont.

Porterfield, Richard L.
In press. A profile of forest industry employment in Montana. USDA For. Serv. Res. Pap. INT-___. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Rohdy, D. D., and R. E. Lovegrove.
1970. Economic impact of hunting and fishing expenditures in Grand County, Colorado, 1968. Colo. State Univ., Fort Collins.

Wallace, Robert F., and Daniel R. Blake.
1966. Montana travel study. Bur. Bus. Econ. Res., Univ. Mont., Missoula.

POLZIN, PAUL E., and DENNIS L. SCHWEITZER
1975. Economic importance of tourism in Montana. USDA For. Serv. Res. Pap. INT-171, 19 p. (Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.)

About one-fourth of each tourist dollar accrues to Montanans as income; the proportion is smaller for expenditures by outdoor recreationists. It is unlikely that growth in tourism could offset income losses resulting from even moderate declines in timber harvesting. Tourist and timber industry employment differ in many respects.

OXFORD: 907.2: 624.
KEYWORDS: outdoor recreation, timber industry, Montana, tourism, income, employment.

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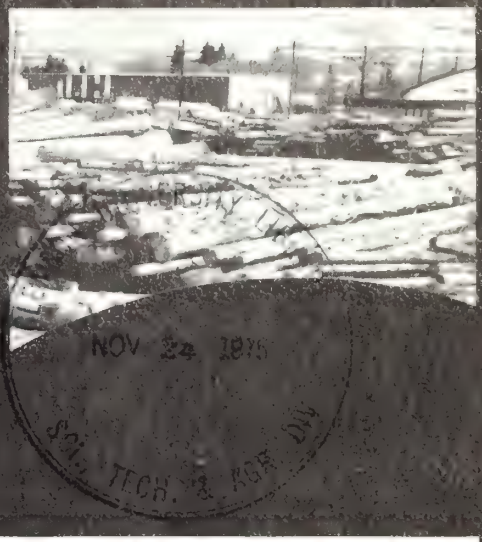

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RICHARD L. PORTERFIELD

USDA Forest Service Research Paper INT-172, 1975
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Richard L. Porterfield

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401
Roger R. Bay, Director

THE AUTHOR

RICHARD L. PORTERFIELD has been Assistant Professor of Forestry, University of Arkansas at Monticello, Monticello, Arkansas, since July 1973. In 1968, he graduated from Ohio State University with a B.S. degree. He obtained his M.S. degree from North Carolina State University in 1970, and his Ph. D. degree from Yale University in 1973. His current research deals with utilization during harvesting and primary wood manufacturing operations, and the importance of forestry to the Arkansas economy.

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ABSTRACT

Employment in Montana's forest products industry is compared to other industries in the State and the United States forest products industry. Forestry employment represents a significant proportion of manufacturing jobs in Montana and the work force is younger, less educated, and less skilled compared to other Montana industries. Earnings in the forest products industry are higher than other State industries and the United States average; however, forestry employment is hazardous. New capital expenditures by Montana's forest products industry have been high yet value added per employee is low.

INTRODUCTION AND MAJOR FINDINGS

The wood products industry is a major part of the total manufacturing industry in Montana. Its importance can be measured in terms of jobs and in terms of payroll. Because the wood products industry is also a part of the basic commodity-producing sector of Montana's economy, many secondary or service jobs depend on forestry-related employment. For the State, there are approximately two service jobs for each job in the basic industries (Montana Economic Study, 1970, part 1, chapter 2). From this relationship, the 8,200 jobs in lumber and wood products in 1972 supported approximately 16,400 employees in service industries. In western Montana, where the industry is concentrated, the impact is even greater. Some 43 percent of the total employment in the eight western counties is directly or indirectly dependent upon the wood products industry; direct employment in 1971 was (Schweitzer and others, 1975):

County	*county employment*
Missoula	14
Flathead	15
Lincoln	27
Sanders	23
Ravalli	12
Lake	10
Mineral	27
Granite	14

It is important, therefore, to understand forestry-related employment in Montana. Information such as personal characteristics of work force, earnings, safety, and productivity for the lumber and wood products industry can provide basic data necessary to judge if the wood products industry is "keeping-up" with other Montana industries in terms of compensation to employees and reinvestment (Zinn 1972; Walton 1974). For example, in 1950 per capita income in Montana was 8 percent above the national average; by 1968 it had fallen to 14 percent below the national average (Montana Economic Study 1970, part 1, chapter 3). Thus, the prosperity of Montanans is falling relative to the national average. Is Montana's wood products industry paying less than the national average wage for the wood products industry?

Another reason for analyzing forestry employment in Montana is to better underst the impacts of changes in forest management policies. Employment and earnings are important considerations when evaluating alternative uses of the forest resource. Th cost of curtailing timber production in an area, for example, must consider induced changes in employment and income.

Briefly, this study finds that:

1. Forestry-related employment is a major component of total manufacturing empl ment in Montana;

2. employees of the Montana wood products industry are generally younger, less skilled, and have less formal education than employees of other major Montan industries;

3. annual earnings in the Montana wood products industry are above the national average for this industry;

4. logging is the most dangerous occupation in Montana; and

5. Montana's wood products industry has led all other industries in new capital investments in recent years but productivity, as measured by value added per employee, has remained low.

PERSONAL CHARACTERISTICS AND EARNINGS

Occupations and Education

Any industry requires a variety of skills. In table 1, skills are categorized by cupation groups for selected industries.

The Furniture, Lumber and Wood Products industry employs very few professional and chnical workers: 1.7 percent of its work force. Of the industries listed, only rail- ads employ proportionately fewer professional people. Paper and Allied Products ploys the highest proportion of skilled and professional workers of any of the manufac ring industries.

Most industries draw heavily upon craftsmen and machinery operators. But the Wood oducts industry also depends heavily upon manual labor: more than one-fourth of its rk force comes from this group. The Paper industry employs proportionately more illed people.

[illegible]

Industry	Profes-sional, tech-nical	Managers, adminis-trators	Sales workers	Clerical workers	Craftsmen	Machine opera-tors	Laborer	hold	Index of laborers)
NATIONAL AND MONTANA [illegible]									
United States	15	[illegible]	7	18	14	[illegible]	[illegible]	[illegible]	[illegible]
Montana	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]									
Agriculture, forestry and fisheries	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mining	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	3	[illegible]	[illegible]
All manufacturing	[illegible]	7	[illegible]	[illegible]	[illegible]	[illegible]	11	[illegible]	[illegible]
Furniture, lumber and wood products	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]
Paper and allied products	7	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	1	[illegible]
Primary nonferrous industries	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Food and kindred product	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11	[illegible]	[illegible]
Railroad	[illegible]	1	[illegible]	17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Entertainment and[3] recreation services	18	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38	[illegible]
Percent of occupation group having at least a high school education	[illegible]	[illegible]	75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1] See appendix for composition of industry groups.
[2] Less than 0.5 percent.
[3] Includes theatrical productions, dance schools, bowling alleys, etc.

Adapted from table 180 and table 179 (percent of occupation group completing high school) of census of popu[illegible]. characteristics of the population: Montana 1970. U.S. Dep. of Commer., Bur. Census, Washington, D.C.

The percentage of Montana's work force having at least a high school education is shown by occupation groups at the bottom of table 1. These percentages were multiplie by the percentages of work force in each occupation group and summed to develop the In of Formal Education in table 1. The higher the index, the greater the proportion of workers who have completed at least a high school education. Forest-related industrie have relatively low indexes. (Educational attainments are directly available by indus tries only for the total United States. See 1970 Census of Population, Subject Report Industrial Characteristics PC(2)-7B, U.S. Department of Commerce, Washington, D.C.)

Employment and Age

The age of the work force in each industry is an important indication of the oppo tunities for employment of young people and may indirectly reflect the industrial phys cal requirements. Numbers employed and their age distribution for selected industries are presented in table 2.

Table 2.--*Employment and age distribution for selected industries for persons 16 years old and older, 1970 (composition of industry groups presented in appendix)*[1]

	Total employed	Proportion of work force (years): 16 - 24	25 - 44	45+	Median age
		Percent			*Year*
NATIONAL AND MONTANA TOTALS					
United States	76,553,599	19	42	39	40
Montana	244,608	18	41	41	41
MONTANA INDUSTRY					
Agriculture	30,382	15	34	51	45
Mining	5,877	14	44	41	41
Construction	15,674	11	48	41	41
Forestry related:					
Forestry and Fisheries	2,344	24	48	28	35
Logging	1,377	12	54	35	39
Sawmills, millwork	5,490	16	48	36	38
Misc. wood products	237	23	32	44	43
Paper and allied products	389	10	67	22	35
Other manufacturing:					
Furniture and fixtures	132	18	35	47	42
Stone, clay, and glass	783	8	44	48	44
Primary nonferrous metals	4,670	18	41	41	40
Fabricated metals	537	18	46	36	38
Machinery (except electrical)	503	12	43	45	42
Printing and publishing	2,327	32	40	28	34
Chemicals and allied products	511	12	49	39	40
Petroleum and coal products	867	6	44	50	46
Transportation, communications, and utilities	19,458	11	44	44	43
Wholesale and retail trade	54,525	23	39	37	38
Entertainment and recreational services	1,866	46	24	30	29
Public administration	14,508	10	43	47	44

[1] Adapted from table 187, Census of population, characteristics of the population: Montana 1970, U.S. Dep. Commer., Bur. Census, Washington, D.C.

Forestry-related employment totaled about 9,800 in 1970 (counting only the 2,300 forestry jobs in the Forestry and Fisheries sector). Forestry accounted for about one-third of Montana's employment in manufacturing; however, agriculture, construction, and several of the service industries had more employees.

The age distribution for agriculture reflects an older work force. Over one-half of those employed in agriculture are over 45 years old. Employment in Forestry and Fisheries, which is almost entirely forestry employment in Montana, is characterized by a young work force with a median age five years less than the median age of workers statewide. Ninety percent of the workers in this category are Federal employees of agencies such as the Forest Service and Bureau of Land Management. Only the printing and publishing, and entertainment and recreational services sectors have a higher proportion of young workers. The prevalence of part-time employment may explain the high proportion of young people in the entertainment and recreational services sector.

Logging has a slightly lower median age than the overall State work force, but comparatively few logging workers are under 25. Because the number of jobs in this sector has been declining in recent years (Johnson 1972), it is not surprising that fewer young people are attracted to logging. The small proportion of the work force over 45 years old may reflect the difficult physical requirements of this sector. Miscellaneous wood products manufacturing is attracting a proportionally larger number of young people, but is still characterized by an older than average labor force. Sawmills and Millwork, which includes plywood production, and Paper and Allied Products have comparatively young work forces.

Composition of the Work Force and Unemployment

The experienced labor force represents the total pool from which respective industries can draw trained workers. Montana's work force together with percentages employed and a breakdown by sex and minority group are shown in table 3. Montana has a slightly smaller proportion of women and a much smaller proportion of Negro and Spanish-speaking employees in its work force than is true for the total United States. (Montana's total population also has a smaller proportion of these minority groups than the United States as a whole.)

Males dominated the 1970 experienced labor force in all forestry-related employment, probably because of the physical demands of the work. In the primarily Federal jobs of the Forestry and Fisheries sector, nearly one in five employees were female. More than one-quarter of all females in the State's experienced labor force are concentrated in the wholesale and retail trade sector.

Utilization of the experienced labor force is depicted in the "Employed as a percent of experienced" column. Only the construction, logging, fabricated metal, and entertainment and recreational services industries had unemployment rates of more than 10 percent. The census was taken during the first week in April when weather conditions were severe and when demand for recreation services was low. Persons not employed that week were counted as unemployed; thus, 42 percent of those in logging are shown to be unemployed. Figure 1 shows employment for four sectors by month in 1973. In April, employment was also at a low point for the lumber and wood products industry. Employment in the wood products industry is more stable than employment in either construction or hotels and lodging places. Johnson (1968) has cited the highly seasonal nature of businesses such as the hotel and lodging places that cater to the tourist trade.

Table 3.--*Composition of experienced and employed civilian labor force for selected industries, 1970*

	Experienced labor force		Employed labor force		
	Age 16+	Percent female	Percent of experienced	Percent female	Percent Negro and Spanish speaking
			NATIONAL AND MONTANA TOTALS		
United States	80,051,046	38	96	38	11
Montana	259,612	35	94	35	1
			MONTANA INDUSTRY		
Agriculture	28,891	8	97	8	6
Mining	6,296	4	93	4	2
Construction	17,768	5	88	5	1
Forestry related:					
Forestry and Fisheries	2,479	16	93	19	7
Logging	2,388	2	58	2	(1)
Sawmills, millwork	6,088	5	90	4	1
Misc. wood products	261	22	91	16	0
Paper and allied products	406	1	96	0	3
Other manufacturing:					
Furniture and fixtures	132	20	100	20	0
Stone, clay, and glass	852	12	92	12	0
Primary nonferrous metal	4,764	2	98	2	2
Fabricated metals	602	8	89	9	0
Machinery (except electrical)	524	12	96	11	0
Printing and publishing	2,430	32	96	31	(1)
Chemicals and allied products	515	10	99	10	1
Petroleum and coal products	881	7	98	7	1
Transportation, communications, and utilities	20,183	16	96	16	1
Wholesale and retail trade	57,924	44	94	43	1
Entertainment and recreational services	2,141	47	87	41	1
Public administration	15,175	34	96	34	1

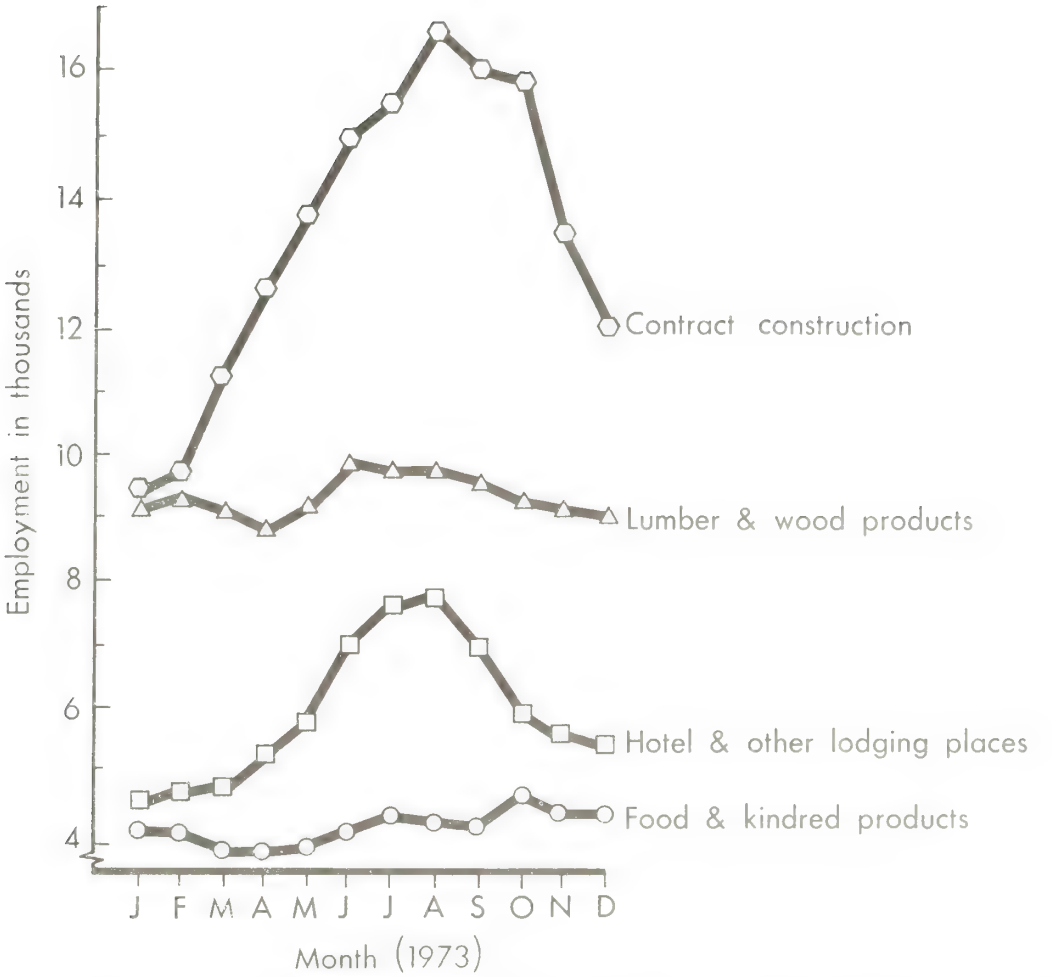
[1]Less than 0.5 percent

Adapted from tables 183 and 184 of Census of population, characteristics of the population: Montana, 1970, U.S. Dep. Commer., Bur. Census, Washington, D.C.

Comparing the proportion of females employed with the proportion of females in the experienced work force shows employment rates for females versus males by industry. If the percentage of females in the employed work force is less than the percent of experienced labor force, the unemployment rate is higher for females than males. Of those industries listed in table 3, the unemployment rate is higher for females in seven industries and higher for males in two industries.

Forestry and Fisheries has a much higher unemployment rate for males than for femal In fact the Census indicates that more females were working than there were available in the total experienced work force in this sector.

The Federal-dominated Forestry and Fisheries sector also has the highest proportion of employees of Negro and Spanish extraction. (Statistics on employment of American Indians are not available.) Agriculture, Mining, and Paper and Allied Products are the other industries where employment of these minorities is greater than the State average.



igure 1.--Employment by month for four Montana industries. (Source: Montana employment and labor force, monthly report, March 1974. Vol. 4(3). Employment Security Division, Dep. Labor and Ind., Helena, Mont.)

Earnings

An industry's contribution to the economy of a State is a function of employee numbers and wages. Although annual earnings may include income from other sources, average wage is generally a good approximation of pay scale when an entire industry is considered. Earnings for Montana and the United States by sex and by industry are compared in tables 4 and 5. The figures cover only the experienced labor force with earnings in 1969. For example, table 3 gives 259,612 as the total experienced work force within the State, while the total experienced work force from tables 4 and 5 (male and female) is 247,519 persons. This means that 12,039 members of the experienced civilian labor force had no earnings in 1969.

Tables 4 and 5 suggest that without exception females earn less than male counterparts in each industry in Montana and United States. However, with the exception of Forestry and Fisheries and the Fabricated Metals industries in Montana, and Logging in the total United States, a smaller proportion of the experienced female labor force worked a full 50-52 weeks in 1969. Therefore, it is difficult to know whether females

Table 1.--*Earnings in selected industries of the male civilian labor force age 16 and older with earnings in 1969*

	Montana				United States	
	Number[1]	Median earnings[1]	Median earnings of those working 50-52 wks.[1]	Percent working 50-52 wks.[2]	Median earnings	Percent working 50-52 wks.
Experienced civilian labor force	165,432	$6,930	$ 7,669	73	$7,620	73
INDUSTRY						
Agriculture	27,726	4,480	5,211	77	3,888	72
Mining	5,987	7,747	8,357	74	8,153	76
Construction	16,721	7,494	8,429	56	7,552	59
Forestry related:						
Forestry and fisheries	2,075	7,739	9,634	64	6,155	61
Logging	2,317	7,611	8,582	48	4,488	45
Sawmills, millwork	5,758	7,073	7,716	69	5,744	67
Misc. wood products	203	6,394	6,976	57	5,397	69
Paper and allied products	397	9,355	9,820	79	8,168	81
Other manufacturing:						
Furniture and fixtures	100	--	--	87	6,040	74
Stone, clay, and glass	743	7,862	8,711	67	7,656	77
Primary nonferrous metals	4,561	7,214	7,510	79	--	--
Fabricated metals	548	6,649	7,580	68	7,880	77
Machinery (except electrical)	455	7,827	8,671	77	8,731	80
Printing and publishing	1,593	7,332	8,144	74	8,614	77
Chemicals and allied products	463	8,373	8,741	86	9,134	84
Petroleum and coal products	813	9,502	10,126	83	9,632	84
Transportation, communications, and utilities	16,732	8,083	8,525	80	8,358	77
Wholesale and retail trade	31,812	6,475	7,327	74	6,602	70
Entertainment and recreational services	1,052	3,792	6,733	51	5,227	52
Public administration	9,883	7,833	8,185	86	8,645	86

[1] Table 188, and
[2] Table 185, Census of population, characteristics of the population: Montana, 1970, U.S. Dep. Commer., Bur. Census, Washington, D.C.

Table 5.--*Earnings in selected industries of the female civilian labor force age 16 and older with earnings in 1969*

	Montana				United States	
	Number[1]	Median earnings[1]	Median earnings of those working 50-52 wks.[1]	Percent working 50-52 wks.[2]	Median earnings	Percent working 50-52 wks.
Experienced civilian labor force	82,087	$2,839	$3,992	51	$3,646	53
INDUSTRY						
Agriculture	1,831	1,647	2,480	65	1,630	51
Mining	214	4,571	5,293	66	5,313	71
Construction	690	3,907	5,354	56	4,707	64
Forestry related:						
Forestry and fisheries	372	5,405	5,946	72	3,868	55
Logging	46	--	--	45	3,736	54
Sawmills, millwork	274	5,315	6,122	65	3,780	58
Misc. wood products	58	--	--	40	3,545	59
Paper and allied products	4	--	--	0	4,537	62
Other manufacturing:						
Furniture and fixtures	27	--	--	52	3,868	58
Stone, clay, and glass	88	--	--	47	4,654	62
Primary nonferrous metals	117	6,058	--	72	--	--
Fabricated metals	46	--	--	78	4,597	61
Machinery (except electrical)	58	--	--	64	4,996	65
Printing and publishing	706	2,761	3,848	54	4,188	59
Chemicals and allied products	52	--	--	35	5,234	67
Petroleum and coal products	60	--	--	67	5,773	74
Transportation, communications and utilities	3,240	4,521	5,245	71	4,894	63
Wholesale and retail trade	22,594	2,342	3,474	52	2,708	51
Entertainment and recreational services	868	850	2,648	28	2,406	40
Public administration	4,726	3,265	4,286	66	5,438	70

[1] Table 189, and
[2] Table 185, Census of population, characteristics of the population: Montana, 1970, U.S. Dep. Commer., Bur. Census, Washington, D.C.

were actually paid less per hour or simply worked fewer hours. Nevertheless, a comparison of median earnings of persons working 50-52 weeks (tables 4 and 5) shows female earnings are still less than earnings for males. There are many kinds of jobs within each industry, but even so, females must occupy proportionally more of the low-paying jobs.

Females enjoy their second highest earnings in the Forestry and Fisheries sector, probably because of Federal employment. For those females working 50-52 weeks, however, Sawmills and Millwork yielded higher earnings than any other industry in Montana and much higher than the United States median for females in the Sawmills and Millwork industry (table 5). Wholesale and retail trade, which employs the largest portion of Montana's female labor force, ranks quite low in terms of median annual earnings for women. Overall, Montana women earned 22 percent less than the average female in the United States in 1969. In support of this conclusion, Polzin (1970) found that average annual income (earnings plus proprietor income and transfer payments) for both females and males was lower than the national average.

Montana males, with earnings in 1969, earned 9 percent less than the average United States male. However, in every forestry-related industry Montana males earned more than their United States counterparts.

Industry	*Earnings as a percent of National Average*
Forestry and Fisheries	126
Logging	170
Sawmills, Millwork	123
Misc. Wood Products	118
Paper and Allied Products	115

Kaiser (1973) found that volume of timber per acre and number of employees per firm were the most important variables in his attempt to explain interregional wage differences in the forest products industry. Both variables had a positive effect on wage rate. Table 6 indicates that Montana is above the United States average with regard to both volume per acre and employees per firm.

Every forestry-related industry except miscellaneous wood products manufacturing also has higher than State median earnings. Earnings in Paper and Allied Products rank second, only behind earnings in the Petroleum and Coal industry in the State. It should be pointed out, however, that Montana's forest industry could still contribute to the below-national-average per capita income if forest industry, nationwide, is a low-paying industry.

Only 48 percent of the Montana males in the Logging sector worked 50-52 weeks in 1969. Yet this figure is still higher than the total United States figure, which includes areas such as the Southern United States that are much more favorable for year-round logging. And, though the distribution of earnings may be seasonal, males in Logging received relatively high earnings. Comparing all employees working 50-52 weeks, earnings of loggers ranked seventh among industries listed in table 4. The seasonal nature of employment in forestry-related industries, Construction, and Entertainment and Recreational Services is apparent in tables 4 and 5.

Table 6.--*Volume of timber on commercial forest land and average number of employees in the lumber and wood products industry by region.*

Region[1]	Cubic feet/acre[2]	Average number of employees/firm[3]
United States	1,430	20
North	980	19
South	958	16
West	2,751	31
Pacific Coast	3,717	[4]N/A
Rocky Mountain	1,691	N/A
Montana	2,076	21

[1] Delaware and Maryland included as part of North for cubic feet/acre but are part of South of number of employees per firm.

[2] Tables 4 and 10 of appendix 1 of "The outlook for timber in the United States, 1973." For. Resour. Rep. 20, U.S. Dep. Agric. For. Serv., Washington, D.C.

[3] Preliminary report, 1972, census of manufactures: area series (Montana) and industry series (U.S. and Regions), Bur. Census, Dep. Commer., Washington, D.C.

[4] N/A = not available.

INDUSTRY SAFETY

Occupational safety is a very important part of the work environment. The desirability of a specific job, even if well paid, may be significantly reduced if the job involves high risk of injury or death. Montana workers suffered 25,821 injuries in fiscal year 1972.[1] A total of 6,927 or 29 percent of these injuries involved some lost work time; the national average is 30 percent of total injuries.[2]

There were 56 work-related fatalities in Montana in fiscal year 1972, which was up slightly from the previous year but down from the average of 75 fatalities per year during the 1950-1960 period. Ten of these deaths occurred at logging or sawmilling operations and accounted for 71 percent of the deaths in the manufacturing sector. Five of the forestry-related deaths were due to falling trees or logs.

Compensation for work injuries is paid by employers through a State Workman's Compensation program. This cost is very high:

Montana, all industries, 1972-73

Compensation benefits paid	$ 8,527,768
Hospital, medical, and burial benefits paid	4,821,533
	$13,349,301

Each firm in an industry pays a basic rate per 100 dollars of payroll that depends on that industry's workman's compensation costs over the previous 5 years. This basic rate is a good general index of the safety conditions in each industry. However, large self-insured organizations, such as Montana's only pulpmill, are not included in this statewide program. Table 7 contains rates for selected industries and occupations in Montana. Logging and lumbering has the highest workman's compensation rate of any industry or occupation in Montana. Sawmill employment is also a high-risk occupation according to this index of safety.

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[1] From "Work injuries in Montana 1973," Workmen's Compensation Division, Dep. Labor and Industry, Helena.

[2] Bureau of Labor Statistics, "BLS reports detailed results of 1972 survey of occupational injuries and illness," News Release, May 2, 1974. Dep. Labor, Washington, D.C.

Table 7.--*Workman's compensation and occupation insurance rates in Montana for selected occupations (Fiscal year 1973)*[1]

Occupation	Rate per $100 of payroll
Logging or timbering--including contract log hauling	$25.00
Aircraft operation--dusting, spraying, herding, stunt-flying	24.50
Coal mining--underground	15.25
Sawmills	14.60
Street or road construction--rock excavation	13.90
Tie, post, and pole yards	8.60
Wood preserving	8.60
Veneer manufacture	6.95
Iron or steel workshop	6.95
Planing or moulding mills	6.25
Street and road construction, paving, or repairing	5.70
Veneer products manufacture	5.20
Policemen	5.05
Smelting, sintering, or refining (other than lead)	4.15
Firemen	3.60
Coal mining--surface (nonauger)	3.25
Millwright work	3.25
Telephone or telegraph companies	3.05
State--professional, administrative, and building maintenance	2.80
Restaurants, beer--including entertainment	2.45
Oil refining--petroleum	2.30
Food sundries manufacturing (excluding cereal milling)	2.15
Department stores--retail	.70
Colleges or schools--professors, teachers	.20

[1] From Montana rules, classifications, and rates for workman's compensation and occupational disease, rates section, 1972. Dep. Labor and Ind., Div. Workman's Compensation, Helena, Mont.

The total workman's compensation benefits paid for several Montana occupations are shown in figure 2. Because these benefits reflect changes in numbers of employees as well as the occurrence of accidents, the numbers of disabling (time lost) injuries per 1,000 workers are also presented for major industry groupings in table 8. These rates for Montana are below the corresponding rates for the United States except in construction and manufacturing. For manufacturing, the explanation lies in the very high accident rates in the wood products industries. Because wood products make up a third of all manufacturing in Montana but only 3 percent in the United States, the Montana manufacturing accident rate is much higher than the national average.

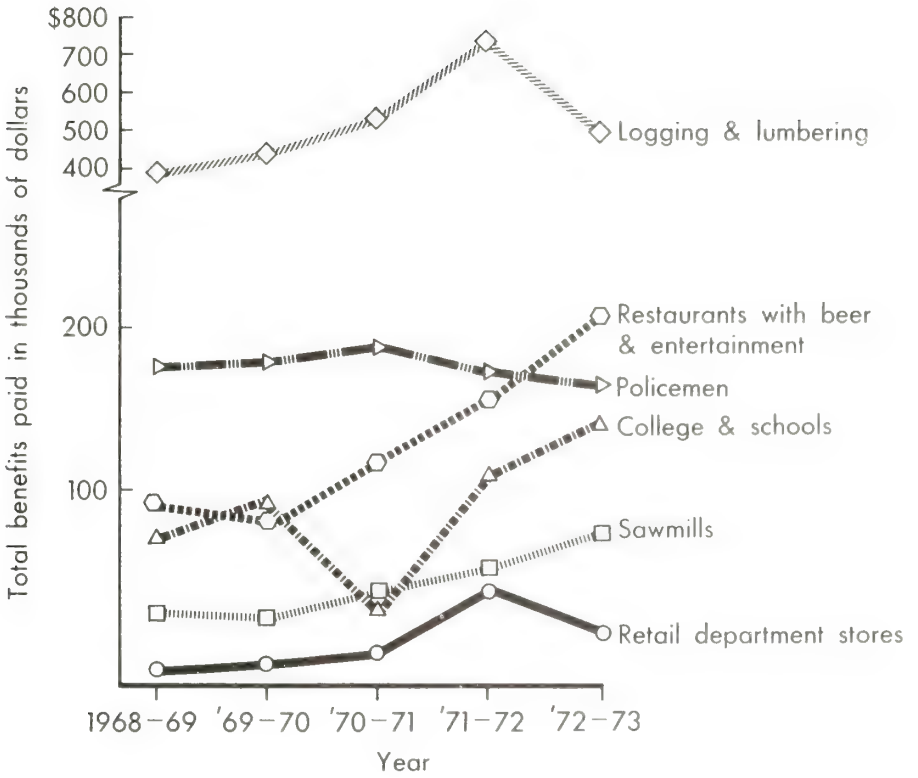

Figure 2.--Total benefits paid to employees for several Montana occupations.

Table 8.--*Disabling work injuries per 1,000 workers*[1]

Industry divisions	Montana		United States
	Deaths	Accident rate[2]	Accident rate[2]
Agriculture	3	[3]N/A	N/A
Mining	9	75	N/A
Construction	10	106	60
All manufacturing	14	86	42
Logging	8	N/A	162
Sawmills	2	N/A	96
Transportation, communications, and utilities	6	23	45
Finance, insurance & real estate	0	4	8
Trade	5	25	28
Services[4]	2	15	20
State and local governments	7	16	N/A

[1]Montana--Fiscal Year 1972-73; U.S.--Calendar Year 1972.
[2]Rate based on absolute number of workers for Montana.
Rate based on 200,000 hours worked for each 100 full-time employees for United States data.
[3]N/A = Not available.
[4]Includes, for example, agricultural services, hunting, forestry, hotels, auto repair, educational services, etc.

"Work injuries in Montana, 1972." Workman's Compensation Div., Dep. Labor and Industry, Helena, Mont.; and "BLS reports detailed results of 1972 survey of occupational injuries and illness," 1974, Bur. Labor Stat. U.S. Dep. Labor, Washington, D.C.

LABOR PRODUCTIVITY

The productivity of employees--that is, the economic value of what they produce relative to the costs of production--provides an index of the health of an industry. In this section, production worker employment and wages, capital investments, and economic values characterizing Montana's wood products industry are compared with other State manufacturing industries and with the national wood products industry.

Hours Worked and Wages

The total number of production workers in the State has increased only slightly in recent years, while the average number of hours worked per production worker has decreased slightly (table 9). The 1972 data indicated that logging employees worked 176 hours or 4 1/2 weeks less during the year than the average production worker in Montana and received only 70 percent of the annual wage of the average Montana production worker. In 1967, sawmill workers worked more than an average number of hours for less than average wages; in 1972, they worked on the average 3 weeks longer for more than average pay.

Table 9.--Employment, hours, and wages in Montana manufacturing industry[1]

	Production Employees		Man-hours per employee[2]		Number of 40 hr work-week equivalents	Wages paid per production worker		Production wages as a percentage of total payroll, cost of materials and capital investment
	1967	1972	1967	1972	1972	1967	1972	1972
				MONTANA				
	[illegible]	[illegible]	1,994	[illegible]	49.7	$5,988	$8,143	9.8%
				INDUSTRY[3]				
Food and kindred products	[illegible]	[illegible]	[illegible]	[illegible]	52.4	$5,818	$8,048	7.5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50.7	4,688	7,851	24.8
[illegible]	1,600	1,600	[illegible]	1,812	45.3	6,188	5,688	27.6
[illegible]	[illegible]	4,200	2,083	2,119	53.0	5,750	8,619	26.1
Millwork and [illegible] products	1,200	[illegible]	2,000	2,000	50.0	5,667	8,250	20.8
Printing and publishing	[illegible]	800	1,778	1,750	43.8	5,778	7,750	31.8
[illegible] products	[illegible]	300	1,667	2,000	50.0	5,667	7,667	[illegible]12.4
Petroleum and coal	[illegible]	600	2,333	2,000	50.0	8,833	12,000	3.5
Stone, clay, and glass products	[illegible]	[illegible]	1,857	[illegible]	57.2	5,571	9,286	19.0
[illegible] products	[illegible]	300	1,667	2,000	50.0	5,333	7,667	19.3
[illegible]	200	[illegible]	1,500	[illegible]	43.8	3,500	3,250	38.2

[1]Census of Manufacturing: area statistics, vol. III, 1967, and preliminary report for Montana, 1972. U.S. Dep. Commer., Bur. Census, Washington, D.C.
[2]Total number of hours worked by production workers divided by the number of production workers.
[3]See appendix for Composition of industry groups.
[4]Does not include an amount for capital expenditures which was withheld to avoid disclosing figures for individual companies.

From 1967 to 1972, the lumber and wood product industry annual [illegible] tion workers improved from 78 to 96 percent of the average wage in the State. The wood products industry is labor intensive; some 25 percent of its total cost of business (total payroll, cost of raw materials, and capital expenditure) were wages to production workers. The petroleum and coal products industry had the highest annual wage and the lowest proportion of production workers payroll to total costs. For the State as a whole, only 10 percent of total manufacturing costs was due to wages for production workers.

The wood products industry showed an interesting response to the general economic recession of 1970 (so defined by the National Bureau of Economic Research). Some industries reduced their numbers of employees while others reduced the number of hours worked per employee. The following figures indicate the approach taken by the wood products industry as a whole and by the sawmill sector:

Lumber and wood products:

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Number of production employees	8,400	8,000	6,200	6,500	7,400
Hours/employee	2,039	2,012	2,000	2,031	2,027

Sawmills and planing mills:

Number of production employees	5,300	5,000	3,800	4,000	4,200
Hours/employee	2,083	2,040	2,0[illegible]	2,125	[illegible]

Sources: 1967, 1972--Census of manufacturing;
1969-1971--Annual survey of manufacturers.

The wood products industry seems to have responded to the economic slowdown of 1970 by reducing number of employees and hours per employee, with the major response in terms of number of employees. The response in the sawmill sector was to reduce the number of employees. This response is not unexpected because much of the wood products industry's labor force is unskilled.

Capital Investments and Value Added

As an index of productivity, value added per employee has the advantage of placing all industries on a common basis. Value added and new capital expenditure are shown in table 10. Total value added steadily increased for all Montana industries from 1963 to 1972. The same is true of value added per production employee hour except for logging camps and contractors, fabricated metals, chemical and allied products, and miscellaneous manufacturing. Value added per employee hour is highest in those industries that are least labor intensive (Production wages as a percent of total expenses, table 9). Using this index, in 1972 the lumber and wood products industry ranked only above fabricated metal products and miscellaneous manufacturing.

One reason for making capital expenditures is to improve productivity by employing more efficient equipment. Expenditures to replace or expand existing capital assets have also been increasing statewide. Almost without exception, lumber and wood products have led the way. New capital expenditures in forest industries were down in 1967 from 1963 levels except for millwork and related products (includes plywood manufacturing), but rose again in 1972. Per employee, capital expenditures in 1972 were highest in the stone, clay, and glass products industry; wood products ranked fourth.

Table 10.--*Value added and capital expenditures for selected Montana manufacturing industries, 1963, 1967, 1972*

	Value Added						New Capital Expenditures		
	Total ($Millions)			Dollars/Employee Hour			Total ($Millions)		
	1963	1967	1972	1963	1967	1972	1963	1967	1972
				MONTANA					
	236.2	311.6	457.5	7.44	9.71	13.78	38.6	68.9	75.4
				INDUSTRY					
Food & kindred products	47.5	55.2	64.6	8.49	11.27	14.68	2.9	5.0	6.9
Lumber and wood products	70.7	85.3	147.7	4.76	5.43	9.85	9.8	6.2	15.9
Logging camps and contractors	16.2	16.9	21.5	5.85	5.63	7.41	3.0	--	2.2
Sawmills and planing mills	44.9	53.3	899.0	4.62	5.33	10.10	6.0	3.2	6.0
Millwork and related products	8.3	13.3	27.2	3.68	5.54	11.33	.8	1.4	5.8
Millwork plants	2.7	2.9	4.2	3.56	4.14	7.00	.1	--	.5
Printing and publishing	12.1	16.4	23.7	7.20	10.25	16.93	.5	.3	1.1
Fabricated metal products	3.1	3.5	5.2	8.19	7.00	8.67	.1	.3	.2
Chemical and allied products	5.2	8.2	9.7	11.83	16.40	16.17	.3	1.2	([2])
Petroleum and coal products	--	43.5	43.5	--	31.07	36.25	--	--	.6
Stone, clay, and glass products	11.9	14.3	24.8	9.57	11.00	15.50	12.4	.9	9.3
Misc. manufacturing	2.0	1.5	2.8	9.05	5.00	4.00	([1])	--	.6

[1]Less than $50,000.
[2]Withheld to avoid disclosing figures for individual companies.

Census of manufacturing, area statistics 1963, 1967 (preliminary for 1972), U.S. Dep. Commer., Bur. Census, Washington, D.C.

Net value added per employee hour (value added per employee hour minus wage rate per employee hour) for the lumber and wood products industry was well below the State average throughout the 1963-1972 period and ranked very low among those industries listed in 1972 (table 11). Out of net value added must come all other expenses of manufacturing and a margin for profit. However, even though the net value added in th wood products industry has been low, it may be improving. From 1967 to 1972, the increase from $2.98 to $5.98 was 132 percent, and during the same time the wholesale price index for all industrial commodities (an index of cost of materials) rose only 18 percent. In 1967, net value added per production-employee-hour in the lumber and wood products industry was lower in Montana than in the United States, but by 1972 was higher than the United States average.

In 1972, net value added for sawmills was also higher in Montana than for the Nation, but lower in the logging sector. The State as a whole was in a favorable posi tion. It is noteworthy that although net value added fell in the logging sector from 1963 to 1967, it rose in 1972. Recent technological advances may well have contribute to improvement. Results for logging camps, sawmills-planing, and millwork sectors are shown in figure 3. The 1972 increases are especially apparent in the millwork sector, which includes plywood and particleboard manufacturing.

Annual Survey of Manufacturers data indicate the same general results for the 1963-1972 period, but more frequent information is available. Therefore, a more complete time series is possible. New capital expenditures are shown in figure 4. Lumber and wood products is the leader by far, accounting for over 25 percent of the State total in all recent years. Capital expenditures by subsectors within the lumber and wood products industry other than sawmills and planing mills (represented by the difference between these lines in figure 4) have been increasing at a steady rate. Those industries not shown in figure 4 simply did not have capital expenditure of any significant magnitude.

Table 11.--*Net value added per employee hour for selected Montana manufacturing industries, 1963, 1967, 1972*[1]

	Montana			U.S.
	1963	1967	1972	1972
Overall average	$4.83	$6.71	$9.68	$9.35
INDUSTRY				
Food and kindred products	6.14	8.49	10.84	
Lumber and wood products (total)	2.32	2.58	5.98	5.43
Logging camps and contractors	3.35	3.13	4.27	5.42
Sawmills and planing mills	2.18	2.36	6.03	5.46
Millwork and related products	1.28	2.66	7.21	5.37
Millwork plants	1.15	1.71	5.33	5.21
Printing and publishing	4.32	7.00	12.50	
Fabricated metal products	5.47	3.80	4.84	
Chemical and allied products	9.02	13.00	12.34	
Petroleum and coal products	--	27.28	30.25	
Stone, clay, and glass products	6.81	8.00	11.44	
Misc. manufacturing	6.32	2.67	2.14	

[1]Census of manufacturing, area statistics 1963, 1967 (preliminary figures for 1972), U.S. Dep. Commer., Bur. Census, Washington, D.C.

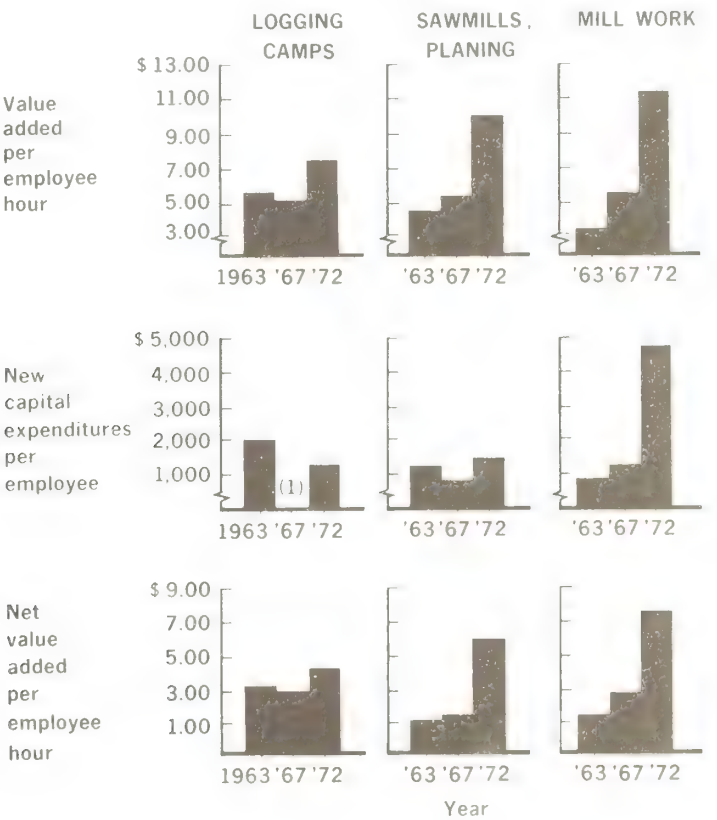

Figure 3.--Productivity and investment indices for sectors of the Montana lumber and wood products industry. (1): Amount withheld to avoid disclosing data regarding individual companies.

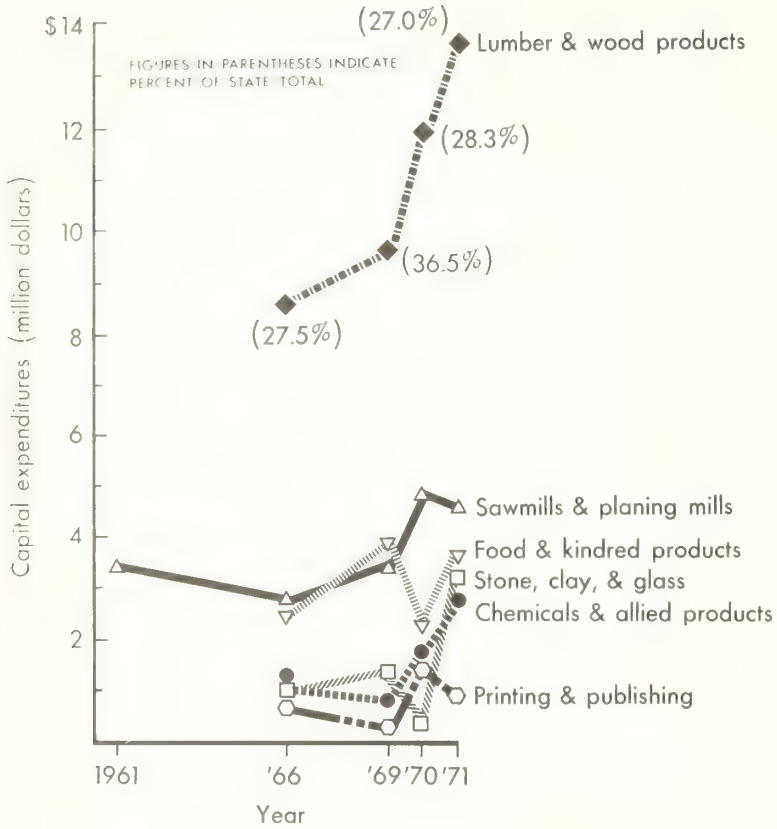

Figure 4.--New capital expenditures for selected industries.

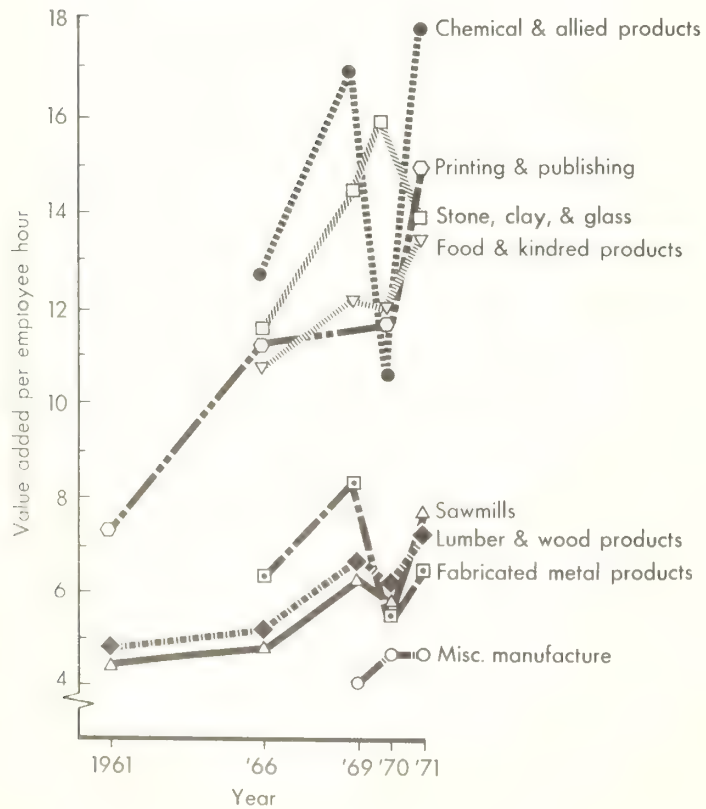

Figure 5.--Value added per employee hour for selected industries.

Value added per employee hour is shown in figure 5. The lumber and wood products industry values are low relative to other industries. Since value added is sensitive to the price of the final product, the dip in 1970 is expected, but even after allowance for change in the wholesale price index for lumber, the value-added line is nearly identical in shape. Thus, figure 5 seems to be a good reflection of productivity for the lumber and wood products industry.

After the heavy expenditures for new capital, one would expect productivity to increase in the lumber and wood products industry, yet response has been mixed. No doubt there is a lag time before new investments bring forth productivity gains, but the historical trend still shows only partial improvement. Perhaps the high capital expenditures have merely been an attempt to keep productivity from falling. Several factors might lead to reduced productivity per worker. A decrease in average tree size would lessen both harvesting and mill efficiency. Furthermore, a shift to less favorable sites would greatly reduce logging productivity. Another impact on logging productivity could be stricter (more costly) regulation of logging on public lands to meet environmental standards.

Of course, value added per employee hour is low for the lumber and wood products industry throughout the United States (fig. 6). However, in comparison with value added for the lumber and wood products industry in the Rocky Mountain region and the United States, Montana's lumber industry dropped from among the leaders to last place from 1956 to 1971. (Rocky Mountain region includes Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, and Nevada.) Even the Rocky Mountain region is falling behind; having been 128 percent of the United States average in 1956, value added per employee hour in the region fell to 106 percent of the United States average by 1971. Though the cause of the productivity index decline for Montana's lumber and wood products industry remains uncertain, it seems clear that the industry is losing ground in spite of substantial new capital expenditures.

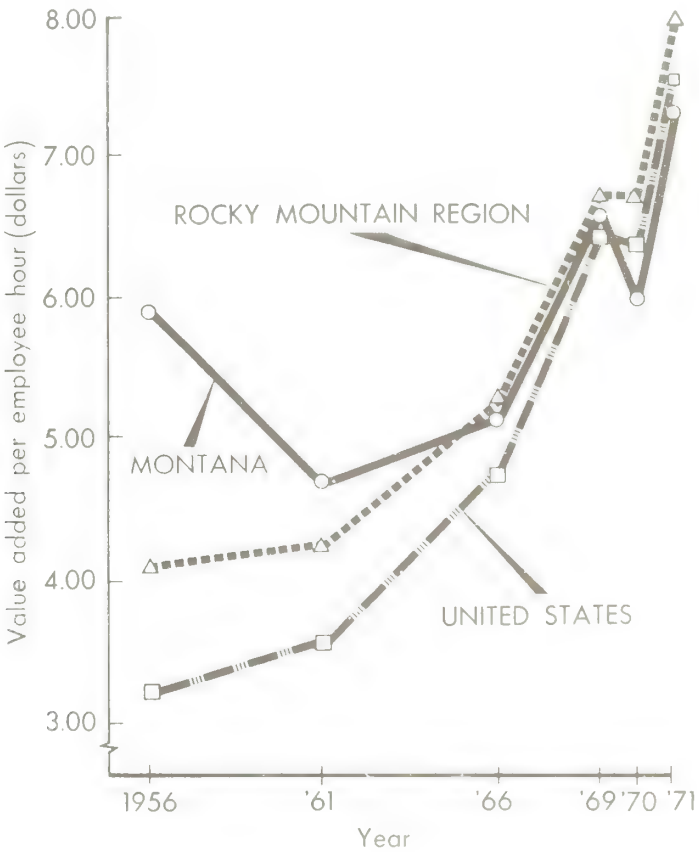

Figure 5.--Value added per employee hour for the lumber and wood products industry.

SUMMARY

Forestry-related employment accounted for only 4 percent of Montana's employed labor force in 1970, but represented over 30 percent of the State's total manufacturing labor force. When compared to the work force of other Montana industries, the work force of the lumber and wood products industry was found to have a younger median age, to be less skilled, and to have less formal education. Employees in the forestry and fisheries sector, which is dominated by employees of Federal agencies directly related to the forest resource, have a very young median age.

There are few females with work experience in the lumber and wood products industry. Again, the Forestry and Fisheries sector is unique in that it employed the entire experienced female work force in that sector in 1970. Without exception, females working in each Montana industry earned less than males, which was also true in the same industries nationwide.

Montana's work force is composed of only 1.1 percent of persons of either Negro or of Spanish ancestry, compared to 10.8 percent for the United States. Forestry and Fisheries had the highest proportion of minority members in its work force (6.9 percent) of all Montana industries. Minority employment in this sector is concentrated in Federal agencies such as the Forest Service.

In 1969, though earnings per employee for all industries in Montana were slightly below those for the United States, earnings in the lumber and wood products industry were above the average for Montana and well above the National average for that industry. Also, the proportion of Montana lumber and wood products industry employees who worked 50-52 weeks was larger than the United States average, even though weather would be more favorable in other parts of the United States.

Nearly 24,000 Montana workers were injured on the job in fiscal year 1972-73. Fifty-six of these injuries resulted in deaths, of which 10 were forestry related. The costs of the injuries including workman's compensation, medical expenses, and burial expenses amounted to over 13 million dollars in 1972-73; these costs are borne by employers. Logging was found to have the highest workman's compensation rate ($25 per $100 of payroll) of any occupation in Montana. Sawmilling also had a high rate. Accident rates for these occupations are very high both in the State and in the Nation as a whole.

The number of production workers in manufacturing in Montana has increased only slightly in recent years. Workers in the seasonally influenced logging industry average 1.5 weeks less work than the average production worker in the State and have earnings substantially below average. The lumber and wood products industry is very labor intensive in comparison with other Montana industries and responded to the economic slowdown of 1970 by reducing its number of employees rather than reducing substantially the hours worked per employee. This was not unexpected because the work force is largely unskilled and therefore should be relatively easy to replace, given Montana's above average unemployment rate.

The lumber and wood products industry has led the State in new capital expenditures or many years, yet productivity of employees, measured as value added per employee our, has remained low relative to other Montana industries. Comparison with lumber nd wood products productivity in the United States and the Rocky Mountain region re- ealed that productivity is indeed low in this industry nationwide. Yet, Montana's ood products industry seems to be falling behind other States in value added per mployee. It is speculated that the large capital investments may have been required imply to keep productivity from falling even further in the face of factors such as ecreasing average tree diameter and the logging of less accessible areas.

PUBLICATIONS CITED

ureau of Business and Economic Research.
1970. Montana economic study. Two parts of three volumes each. Sch. Bus. Adm., Univ. Mont., Missoula.

ohnson, M. C.
1972. Wood products in Montana. Mont. Bus. Q., vol. 10(2). Bur. Bus. and Econ. Res., Univ. Mont., Missoula.

ohnson, M. C.
1968. The tourist industry: some second thoughts. Mont. Bus. Q., vol. 10(1). Bur. Bus. and Econ. Res. Univ. Mont., Missoula.

aiser, H. F., Jr.
1973. Interregional wage differentials in the forest products industry. For. Prod. J. 23(7).

ontana, State of.
1974. Montana employment and labor force, March 1974. Employment Secur. Div., Dep. Labor and Industry. Helena, Mont.

olzin, P. E.
1970. Structural determinants of wage and income levels in Montana. Bur. Bus. and Econ. Res., Staff Study, Univ. Mont., Missoula.

chweitzer, Dennis L., Robert E. Benson, and Richard J. McConnen.
1975. A descriptive analysis of Montana's forest resources. USDA For. Serv. Resour. Bull. INT-11, 100 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

alton, R. E.
1974. Improving the quality of work life. Harvard Bus. Rev. 52(3):12, 16, 155.

inn, G. W.
1972. A model for analyzing the contributions of forestry to a region. Unpublished Ph.D. thesis, on file at State Univ. Coll. For., Syracuse Univ., Syracuse, N. Y. Diss. Abstr. 72-23, 567.

APPENDIX

Composition of Industry Groups as Defined by the Census of Population and the Census of Manufacturers.

Industry group	Industries included: Census of population	Industries included: Census of manufacturers
Agriculture, forestry, and fisheries	Agriculture production agricultural services (except horticulture) forestry and fisheries management, tree farms, timber cruising.	
Mining	Metal and coal mining quarrying, crude oil and natural gas extraction.	
Furniture		Furniture and fixture manufacturing--office, household, and public building furniture, mattress and venetian blind production.
Lumber and wood products (in total)		Logging operations, sawmills, planing mills, veneer and plywood mills, wood preserving, etc.
Logging		Logging operations--camps and contractors.
Sawmills		Sawmills and planing mills.
Millwork and related products		Millwork and veneer and plywood manufacturing.
Millwork plants		Door trim, garage doors, railings, window trim, etc. but not veneer and plywood manufacturing.
Miscellaneous wood products		Wood preserving, cooperage, nailed wooden boxes, etc.
Primary nonferrous industry		Smelting and refining of copper, aluminum, zinc, and lead, copper, and aluminum rolling and drawing, casting of brass, bronze, copper, etc.

Industry group	Industries included: Census of population	Census of
Paper and allied products	Pulpmills, papermills, paperboard mills, envelopes, bags, wallpaper, sanitary paper products, etc.	
Food and kindred products	Meat products, dairy products, canned and frozen foods, bakery products, beverages, etc.	
Railroads	Railroads and railway express service.	
Entertainment and recreation services	Theaters, bowling alleys, pool parlors, dance halls and schools, bands, theatrical productions, commercial sports, etc.	
Construction	General building contractors, general contractors (except building), special trade contractors.	
Stone, clay, and glass	Glass containers, brick and structural clay tile, pottery products, concrete block, lime, gypsum products, asbestos products, etc.	
Fabricated metals	Fabricated structural steel, metal doors, sash, sheet metalwork, architectural metalwork.	
Machinery, except electrical	Engines, turbines, and farm machinery, construction and mining equipment, metalworking machinery, food products machines, blowers and fans, typewriters, etc.	
Printing and publishing	Newspapers, periodicals, books, commercial printing, greeting cards, bookbinding, etc.	
Chemicals and allied products	Industrial chemicals, plastics materials, synthetic rubber, drugs, soap, toilet goods, paints, agricultural chemicals, etc.	
Petroleum and coal products	Petroleum refining, paving mixtures, asphalt felts, lubricating oils and greases, etc.	
Transportation, communication, and utilities	Railroads, bus lines, trucking services, water and air transport, radio, telephone, electric and gas utilities, water supply and sanitary services.	

Industry group	Industries included	
	Census of population	Census of manufacturers
Wholesale and retail trade	Food and farm products, hardware, farm equipment, food stores, motor vehicles, drug stores, other retail and wholesale trade.	
Public administration	Local, State, Federal, and international government activities.	
Primary metals industry		Blast furnaces, steel works and rolling mills an finishing mills, primary and seco ary smelting and refining of non-ferrous metals, such as copper, aluminum.
Miscellaneous manufacturing		Jewelry, plated ware, musical instruments, toy athletic goods, pens, pencils, brooms, caskets, buttons, etc.

PORTERFIELD, RICHARD L.
1975. A profile of forestry employment in Montana. USDA For. Serv. Res. Pap. INT-172, 24 p. (Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.)

Compares forestry employment in Montana with employment in other industries within the State and with employment in the forest products industry nationally. Includes comparisons of safety, capital investments, formal educational levels, and productivity.

OXFORD: 963; 661; 304.
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GROWING
FROM
U.S. FOREST
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GAIN AND LOSS OF MOISTURE IN LARGE FOREST FUELS

THE AUTHOR

ARTHUR P. BRACKEBUSCH is National Fire Management Specialist for State and Private Forestry stationed at the Northern Forest Fire Laboratory. He served as a fire scientist, Project Leader, and Chief of Laboratory at the Northern Forest Fire Laboratory from 1958 to 1972. Previous experience included duty with National Forest Administration, the Bureau of Land Management, and private industry. He holds a master of science degree in forestry from the

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Gisborne and G. Lloyd Hayes conceived, designed, and initiated the study. They conducted the study several years before it was passed on to their successors. Continued direction for the study was given by project personnel of the Northern Forest Fire Laboratory and superintendents of the Priest River and Boise Basin Experimental Forests.

Charles E. Hardy of the Northern Forest Fire Laboratory directed the study from 1951 through 1960. Experimental forest superintendents, Austin E. Helmers, Albert R. Stage, John H. Dieterich, James W. Hanover, Robert W. Mutch, and Marvin W. Foiles supervised the summer

Many summer assistants assigned to the Experimental Forests over the period of the study collected and recorded the data.

Student assistants, Armond Joyce, William Bivin, Gerald Parker, and Marvin LeNoue compiled, tabulated, and prepared most of the data for analysis.

Albert R. Stage and Michael A. Marsden of the Intermountain Forest and Range Experiment Station programed and processed the data at Washington State University.

Ralph Wilson and William Gastineau prepared a program, calculated the prediction curves, and plotted the final curves by X Y plotter.

ABSTRACT

Equations for predicting moisture in large fuels were developed from data gathered at Priest River Experimental Forest and Boise Basin Experimental Forest. The most important variables were beginning moisture content of the fuel, duration of precipitation, amount of precipitation, and the sum of the mean temperature of an observation period. Sensitivity and precision of the equations are weak. Predictions could be used as a guide. Moisture content of logs varied according to type of exposure.

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GAIN AND LOSS OF MOISTURE IN LARGE FOREST FUELS

Arthur P. Brackebusch

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

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PREFACE

For many years there has been much interest in moisture studies of forest fuels. The study reported here was in its 17th year when the author became involved. The study was terminated 2 years later. All data were compiled, adjusted, and analyzed; a report was prepared but not published. Continued interest in moisture content of large fuels prompted the author to reexamine the data, computerize the the equations, and rerun the prediction curves along with the addition of a very dry year (1967) and a moderately dry year (1972). The results indicate major differences in large fuel moisture by exposure and season. Unusual years stand out from the average. The equations are useful but should be applied with discretion.

INTRODUCTION

Experience and common sense tells us that moisture content influences how forest fuels burn. Since the very beginning of fire research, men have attempted to measure, evaluate, and predict the moisture content of duff and fuels of various sizes on the ground and in the aerial portions of brush and trees. In 1935, Harry Gisborne, a pioneer in fire-danger rating and fire-season severity ratings, and a leader in fire research, began studying the moisture content of logs, 10 to 12 inches in diameter. He supposed that repeatedly measuring the moisture content at various depths in large fuels would make it possible to rate current fire danger and identify long-term trends. He speculated that dead trees and logs more than 10 to 12 inches in diameter are common components of the fuel in a forest fire. They contribute to the driving energy of a fire to the extent that they are consumed. Seasonal drying determines the readiness of large fuels to be consumed.

Gisborne selected two fire-killed white pine trees that had been down approximately 3 years. From these he cut sections and embedded electrodes at depths from 1/2 to 6 inches in the smaller log and from 1/2 to 9 inches in the larger log. He installed a complete electrode series on the top, the bottom, and each side of the log. Moisture content was determined at each pair of electrodes by measuring electrical resistance with an instrument called a "Blinkometer." His first attempt had serious faults because the method of sealing electrodes appeared to produce erratic results. A second set of logs was prepared using improved sealing material. Moisture was measured at approximately 10-day intervals. Because reliable measurements could not be made when electrodes and log surfaces were wet, sometimes it was necessary to revise the schedules to avoid rainy days. G. Lloyd Hayes conducted this study from 1935 to 1939 and in 1940 reported his findings in a thesis as partial fulfillment of a master of forestry degree at Yale University (Hayes 1940). A summary of results from his thesis follows:

> The relationship between the amount of change in average moisture content of a 12-inch log per 10-day period and four variables was tested. It was found that the amount of rain per period and the moisture content of the log at 1-inch depth at the start of the period correlated best with the moisture

changes. There is much evidence that duration of rain is very important and affects log moisture changes, but no measurements of it were available.

Each of the four logs studied had a definite area or areas in which the moisture content was over 60 percent for at least part of the summer season. Drying of the log occurred from the surface inward. As the drying progressed, the very moist area became smaller and smaller. A very gradual moisture gradient would be found in the dry outer portion of the log, but a very sharp gradient was maintained near the moist area, indicating that there was little tendency for the free moisture to diffuse into the drier portions of the log.

Evaporation occurred from all the log surface with the probable exception of the part in contact with the ground. Rains of short duration penetrated the log only from the top half whereas rains of long duration penetrated to some extent from the lower half also.

Log moisture content did not provide a usable index of seasonal, monthly, or current fire danger severity. There are two main reasons for the failure: (1) fire danger, as now measured, is based upon the moisture content of fine fuels, which respond to weather much more rapidly than logs, and (2) two logs of approximately the same size had such different moisture contents at one time and from one time to another that the results from one were not comparable with the results from the other.

Log moisture was found to decrease continuously, almost without regard to midsummer rain, from the last decade of June, which received approximately 0.50 inch of rain, to the first decade after August 15 that received a similar amount. Rain falling between June 25 and August 15 had practically no lasting effect upon log moisture content.

Fire danger, in fuel types which include much pole and log-sized fuel, can be expected to increase greatly between July 10 and August 15 because of constant moisture losses. The present system of fire danger measurement makes no allowance for any intensification of the cumulative factor of danger during this period.

The evidence indicates that the two main factors which determine how dry a log will become are its moisture content at the beginning of the summer desiccation period, and the length of the desiccation period. The log moisture at the beginning of the period will depend to a large extent on the amount of spring rain. It is therefore believed that a good index of the inflammability of large fuels during late season can be worked out on the basis of the amount of spring rain and the length of the summer desiccation period. A direct measure of log flammability can be obtained by measuring the average moisture content of the logs themselves, provided logs of the same size can be found which will have the same moisture content at any time and which will react the same from year to year.

Hayes recommended that the study be continued. He recommended that logs 6, 12, and 18 inches in diameter be exposed in an open area at Priest River, that the logs be western redcedar, and that logs be exposed both on the ground and above the ground. Hayes stated that careful weather measurements should be made and correlated to log moisture content. Log moisture content would be determined by weighing the whole section. "Blinkometer" measurements would be continued through 1943. The first two logs which were exposed in 1935 were dissected in 1939 and three new ones added. The second two logs added in late 1935 and the three added in 1939 were studied through 1943.

LOG STUDIES

In 1942, as recommended by G. Lloyd Hayes, western redcedar logs of three sizes, 6, 12, and 18 inches in diameter, were exposed on and above the ground, under no cover, and under full-timber cover. Moisture content determinations by whole-log weighing were started at the beginning of the 1942 fire season. This paper is concerned primarily with the 19 years of data collected from the whole-log weighings made from 1942 through 1960. Hayes has already adequately discussed the period from 1935 through 1939. The "Blinkometer" measurements for 1942-43 period were examined as background but were not analyzed as part of this study.

By 1949, considerable saprot and some heartrot were evident in the western redcedar logs that had been exposed since 1942. In the fall of 1949 a completely new set of logs was prepared and exposed for the next season. Again at the end of the 1957 season, all of the logs were replaced in readiness for the 1958 season. This study was terminated at the end of the 1960 season. After the collected data were analyzed, the equations were tested with 1967 and 1972 weather data. These tests are included in the report.

OBJECTIVES

The objectives of this study were:

1. To determine the relationship between moisture content of logs and the seasonal fire danger.

2. To determine and show the effects of weather and other factors that control moisture content of logs.

3. To determine the difference in moisture content of 6-, 12-, and 18-inch-diameter logs, both sound and decaying, at various times, on and off the ground, and under varying exposure conditions.

A tentative fourth objective was to determine the rate of seasoning, seasonal moisture change, hygroscopicity, and rate of decay of several common species as compared to western redcedar. This portion of the study was never carried out. Rate of seasoning, or at least rate of decay, is indicated by weight loss during the time logs were exposed.

PROCEDURES

Selection of logs.--The 1942 series of logs were western redcedar. Cedar was selected because (1) it was considered the most durable of the native woods, hence should change the least from year to year because of decay; (2) it is a common species in much of the Region; and (3) it had been shown by Jenkins (n.d.) to be more sensitive to moisture changes than at least one other native wood, Douglas-fir.

The logs were approximately 6, 12, and 18 inches in diameter and 5 feet long. Log lengths varied as much as 4 inches to allow cutting samples from either end for determining the ovendry weight by proportionate methods. All logs were from dead, mostly seasoned trees free of visible decay and abnormal cracks. All of the 12- and 18-inch logs had been dead at least 3 years, some perhaps as long as 20 years, but were still sound. Five of the 6-inch logs had been dead only 12 to 15 months, the remainder for 3 years or more. Bark and all traces of the cambium layer were removed with a drawknife "Buckskin" (bare or weathered) logs were left unchanged.

An effort was made to obtain logs that were uniformly exposed to air, weather, and soil from end to end. No trim cuts were made close to other cuts, ends, or breaks. To measure moisture content, a sample approximately 1-1/2 to 2-1/2 inches thick was removed from each end of a log. The two samples were removed when the log was first collected, then wrapped in waxed paper and weighed within 2 hours. The logs were smoothed with a drawknife and weighed either on the same day or the day after they were cut.

The two samples from each log were ovendried at 215° F to constant weight and their moisture contents determined. The log moisture content was considered to be the same as the average of the two samples. Ovendry weights of the logs were calculated.

Log ends were moisture-proofed with three coats of aluminum "paint" composed of powdered aluminum mixed with spar varnish.

Exposure of logs.--The logs and poles comprising the large fuels with which this study is concerned are found both on and off the ground, both in the open and under dense timber. The "on ground" logs were laid directly on the grass and mineral soil at the clearcut station, and directly on the natural duff ground cover at the full-timber station. The elevated logs were supported 12 inches above the ground on plank racks (fig. 1 and 2).

Figure 1.--Six-, 12-, and 18-inch logs exposed on the ground and on racks in a clear-cut exposure at the Priest River Experimental Forest.

Figure 2.--Logs exposed under a full-timber canopy at the Priest River Experimental Forest.

Three logs were prepared for each of 12 treatment categories. The categories included three sizes, 6-, 12-, and 18-inch logs on the ground and elevated and exposed in a clearcut and under full-timber canopy. The logs in each size class were numbered consecutively and their locations determined by lottery.

Observations.--A pair of rails provided a firm and level foundation along which a portable platform scale was moved to the logs. The logs were weighed to an accuracy of ±1 percent of their dry weights. The scales were graduated to 1/4-pound increments, but attempts were made to estimate smaller subdivisions so even the lightest 6-inch logs (which weighed only 16 pounds) would be measured to an accuracy of ±1 percent. Less precision was necessary in weighing the 12- and 18-inch logs.

Each log was weighed and its moisture content computed on approximately the 5th, 15th, and 25th of each month from May 5 through October 25. If precipitation fell, weighing was postponed until the day after it stopped. Logs were always weighed in the early afternoon to avoid diurnal moisture fluctuations.

A weather station for determining standard fire-danger rating was operated at the clearcut site. Afternoon measurements included half-inch fuel stick moisture content, precipitation, wet bulb, dry bulb, wind direction and velocity, daily maximum and minimum temperature, and hygrothermograph measurements.

Duration of observations.--The study was designed to be reevaluated within 3 years and modified if necessary. No evaluations or modifications were found in the records or data, except that in 1949 a completely new set of logs was placed in service. In 1949 Gisborne included the following notations along with the ovendry weights of the new logs:

> In distributing these logs to their future spots, in full sun and full shade, on the ground and supported off the ground, the three main objectives of this study must be considered. These are: (1) to determine differences in time--one year, one month, and one 10-day period from another; (2) to determine differences in exposure, i.e., full sun vs. full shade; and (3) to determine differences between contact and no contact with the ground.
>
> As far as time differences are concerned, it would seem to be unimportant whether the heaviest logs of any size are in the open or the shade, on the ground or off it. But to be able to estimate differences in log moisture due to exposure and ground contact, it seems desirable to have some of the heaviest and some of the lightest at both exposures and both on the ground and off. To accomplish this the following system will be used:
>
> The heaviest log of each size will be placed at the clearcut site and on the rack, the next heaviest at the full-timber and on the rack, the next at the clearcut and on the ground, and the next at the full-timber on the ground. Then place the lightest log of that size at the clearcut on the rack, the next lightest on the full-timber rack, the next at the clearcut ground, and the next at the full-timber ground. That uses 8 of the 12 logs of each size and leaves the 4 middleweights. They can be distributed at random.
>
> To obtain a basis for comparing the new large logs with the old, one old log of each size and exposure on ground and on rack should be kept and weighed when the new ones are weighed in 1950. The log kept in each case should be the one which has been least damaged by past weighings and appears to be the least decayed.

To aid in correcting the moisture content [illegible] allow for mechanical and other losses of OD weight, a 6-inch thick section should be sawed from the approximate center of each of the 25 logs to be discarded. The whole log should be weighed, then that section sawed out and weighed, then that section ovendried and its moisture content compared with that of the whole log. While this will not give us a precise measure of loss of OD weight, the work required to get a full accurate measure does not seem justifiable.

I found no evidence that the ends of the second series of logs were treated with powdered aluminum and spar varnish.

A third series of logs was prepared in the late summer and fall of 1957. These logs were exposed following the 1957 field season in readiness for the 1958 season, but were not end-treated. This series of logs was observed until the study was terminated in November 1960.

When the third series of logs was installed in 1957, the 1949-1957 series was stacked but not dissected for determination of ovendry weight. Stacking apparently accelerated rate of decay. Much of the sapwood crumbled by the next season; consequently it was not possible to determine rate of decay for the 1949-1957 logs.

Enough extra logs were prepared at Priest River in 1957 to establish an identical clearcut exposure at the Boise Basin Experimental Forest at Idaho City, Idaho. The logs were trucked to Idaho City and installed in 1957. Observations were made during 1958, 1959, and 1960.

Uncorrected log moisture data were used several times during and since the 19-year study period to develop fire-danger rating indices. However, none of the data was corrected for weight loss until after termination of the study. Final ovendry weights were determined for all logs of the first series upon termination of their exposure. Unfortunately, the second series was stacked but not immediately sectioned for ovendry determination. Accelerated decay made it impossible to determine a final ovendry weight at the end of the exposure period. The third series was sectioned and calculated like the first series.

Sections were cut from the exposed logs and ovendry weights were calculated the same way as the initial ovendry weight had been determined earlier. The difference between original and final ovendry weight determined at the end of the exposure period was attributed mainly to decay. However, not all the weight differences between initial and final ovendry weights could be explained as decay loss. Inherent errors in the determination of the initial and final weights are quite apparent. Absolute uniformity of density and moisture content throughout the logs must be assumed in order to accept proportionate weight determinations. In actuality, neither moisture nor density is likely to be uniform. Hayes found great variation in distribution of moisture in logs. Density is also variable, particularly in or near knots at the branch whorls. Actual rate of decay was not known.

Considering the probable sources of errors, weights were simply adjusted biennially rather than annually. Some logs and their corresponding data were discarded prior to analysis because in some cases, weight loss was so large that it indicated either extreme rate of decay or an error in either the initial or final ovendry determinations. In a very few cases, logs apparently gained weight. This would also indicate an error in initial or final ovendry weight.

The remaining logs were treated as groups, not as individuals. For example, all 18-inch logs on the rack in the clearcut exposure constituted a group. Likewise, all

12-inch logs on the rack in the clearcut exposure were another group. The three log sizes on two crown-cover exposures and on two exposures relative to ground position comprised 12 groups or 12 exposures. The log weight loss was distributed over the exposure period.

Weight loss was distributed based on the following observations:

1. No visible decay was apparent during the first several years of exposure.

2. No significant weight loss was found for the logs exposed for the short period of 1958 through 1960.

3. A memorandum to J. S. Barrows from R. M. Lindgren of the Forest Products Laboratory dated January 9, 1952, suggested that the rate of decay once established tends to be linear.

Lindgren states:

> When wood that is entirely sapwood is rotted in the laboratory, decay usually proceeds on a straight-line basis more or less. This is particularly true up until the time that the wood becomes thoroughly penetrated by the decay fungus and therefore heavily decayed. . . .
>
> . . .If the deterioration that has occurred in your case involves sapwood almost entirely and if such sapwood hasn't been badly decayed for a long period of time, your best bet would be to assume that rotting had occurred at a straight-line rate.

Weight loss was distributed over the years of exposure to both the 1942-1949 and the 1949-1957 series of logs as follows:

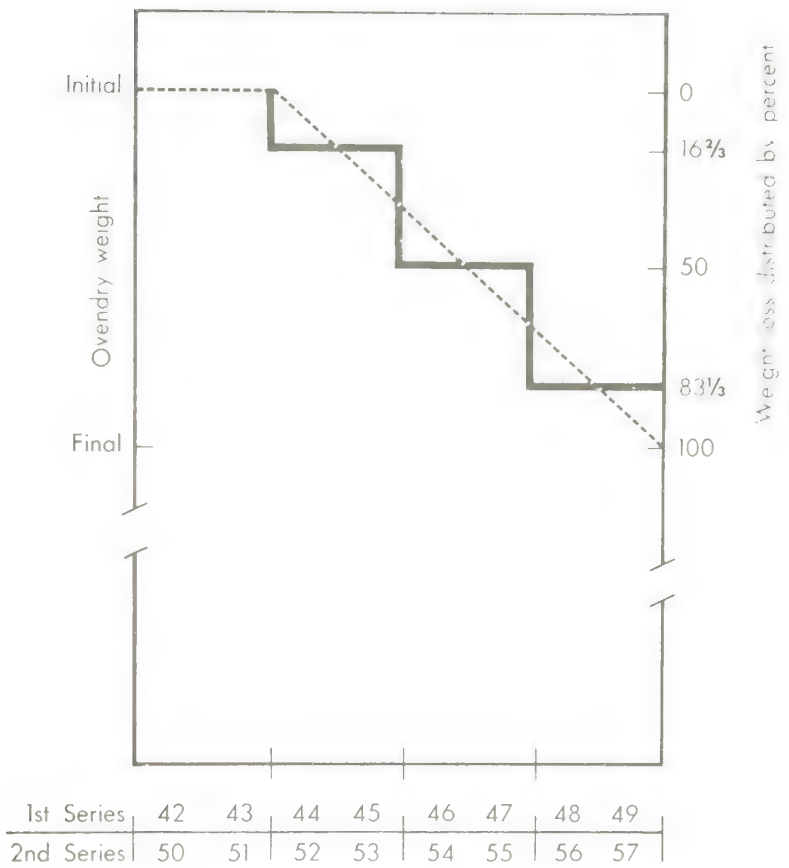
No loss was shown for the first 2 years; then the loss was considered linear. Subsequent corrections were made at 2-year intervals (fig. 3). No loss was applied to the 1958-1960 series.

The differences between the wet weight observations and the adjusted ovendry weights were determined. These differences converted to moisture content in percent were plotted for each group of logs by date for each year of the study. Moisture curves in appendix A show seasonal and yearly differences. Differences between "elevated" and "on-the-ground," and between "full-timber" and "clearcut" are evident.

The first objective of this study was to relate the moisture content of large logs to severity of fire season. Data that expressed fire season severity had to be prepared for such a comparison. Fire records from Kaniksu National Forest were evaluated. All Individual Fire Report Forms (formerly 929, now 5100-29) prepared by personnel of the Kaniksu Forest were examined for the period 1942 through 1960. These data were tabulated by fire cause, size, and date of discovery. Fires were classed as man-caused and lightning-caused and tabulated by periods of time to coincide with the log moisture observation periods. Fires were further separated into five standardized size classes as follows:

Class A--0.25 acre or less
Class B--0.26 to 9.99 acres
Class C--10 to 99.99 acres
Class D--100 to 299.99 acres
Class E--300 or more acres

Figure 8.--Weight loss adjustment schedule for logs. The total and final ovendry weights were calculated for each size group and each type of exposure of logs. No weight loss was applied for the first 2 years, 16-2/3 percent of the loss was applied to the second 2-year period, 50 percent to the third period, and 83-1/3 percent to the fourth period. No loss was applied to the 1958-1960 log series.



The largest body of data concerned study objective Number 2 and dealt with factors that influence gain or loss of moisture in logs. These data were primarily the calculated log moisture content change during an observation period and the daily weather observed during the same period.

The percent change of moisture content was determined for each 10-day observation period. Whenever an observation was missed, the preceding and subsequent periods were lost because no gain or loss could be determined for those periods. Periods of 11 days, such as July 26 through August 5, were treated as 10-day observation periods.

The choice of variables for analysis and correlation tests was based on previous studies of wetting and drying of wood and other cellulosic material. Most studies have been conducted under single or constant environmental conditions.

Cellulosic materials exposed to a constant environment will eventually reach a state of moisture equilibrium, a condition where the gain or loss of moisture is balanced so there is no net change. Not all materials exposed to the same environment reach identical equilibrium moisture content. However, any one material will reach an equilibrium condition dependent upon the temperature and relative humidity of the environment. Byram and Jemison (1943) found that equilibrium moisture content may be altered somewhat by the single or combined effects of solar radiation and wind.

These factors may effectively alter the environment to the degree that the temperature around the cellulosic material is changed. Surface relative humidity will also be influenced by the temperature of the material and the rate at which moisture is brought to or removed from the surface of the material.

The rate at which a material reaches moisture equilibrium is a function of its size and thickness. Very small particles reach equilibrium rapidly. Large, coarse particles respond slowly. Within any forest type one can find a wide range of particle sizes. Some will reach equilibrium moisture content in minutes. Larger materials such as logs may require weeks, months, or even years. The temperature, relative humidity, wind, and intensity of solar radiation are constantly changing in the forest. This, together with the effects of free water deposition as dew, rain, or snow, results in dead forest materials constantly seeking new moisture equilibrium. The very fine materials respond quickly and are able to stay at or near equilibrium. Most forest materials, though, never attain a state of moisture equilibrium.

As illustrated by Hayes' conclusions discussed earlier, moisture inside logs and other large materials is constantly moving. Depending upon the history of surface wetting or drying, moisture gradients develop within a log. These cause moisture to move outward to the surface or inward to the center, or even both directions at the same time, from areas within the log that are wetter or drier than both the center and the surface of the log.

Except after long periods of drying, water in the inner portions of a log (though moving about) seldom escapes from it. Consequently, this water becomes a part of the constant weight of the log. Over short time periods, weight changes of whole logs reflect moisture gained or lost in only the outer shell. The shorter the wetting and drying cycle, the shallower this shell will be. The magnitude of moisture change in this outer portion of a log is seriously obscured when one weighs the whole log, which includes the constant water load. For example, if the outer 1/2 inch of a 6-inch log and the outer 1/2 inch of an 18-inch log are saturated by the same rain and both logs are weighed, the 6-inch log will show a greater percent of weight increase. Thus, if one weighs the whole log, the apparent influence of environment upon log moisture content is dependent upon log size.

Integrating all of the constantly changing environmental factors that control log moisture content is beyond the scope of this study. A major purpose of this study was to simply correlate log moisture content to fire season severity and develop a method for predicting from fire-weather data, log moisture content by log size, exposure, and forest cover.

The variables chosen for analysis described fuel size, length of day and night, temperature, atmospheric moisture, evaporation potential, and amount and duration of free water deposition. The variables were:

X_1 Day length/12

X_2 Precipitation intensity (amount/hours)

X_3 Sum of the daily mean temperatures minus sum of the dewpoints at 1600

X_4 Sum of dewpoint at 1600

X_5 $\dfrac{\text{Sum of the daily mean temperatures minus sum of the dewpoints at 1600}}{\text{Sum of the daily mean temperatures}}$

X_6 Moisture content of the log at the beginning of the period

X_7 Precipitation in hours to the nearest 0.5 hour

X_8 Precipitation amount in inches and hundreds

X_9 Sum of the daily mean temperatures

Y Gain or loss of moisture as a percent of ovendry weight

ANALYSIS

Data analysis is presented in the same order as the study objectives. The first tests were to determine relationships between log moisture and the seasonal factor of fire danger.

Many tests of the data were made--numbers of fires, sizes of fires, man-caused fires as opposed to lightning fires, and acreage burned--but no positive relationships were found. The percentage of fires per year that exceeded certain sizes seemed to be the best measure of severity of a fire season. The percentage of fires that exceeded Class A and Class B was compared with moisture content of logs during the most critical period.

All of the fires in a season were used in the analysis; however, the mean moisture content of the logs was used only for the period July 1 through September 5. This was the lowest segment of the moisture curves and was considered to be representative of the dryness of the season. In an attempt to use log moisture as a measure of potential fire season severity, the data were compared with several other accepted seasonal severity rating systems. One of the first rating systems used was Gisborne's method that compared seasonal fire-danger data against a "worst probable" year. Worst probable was defined as a year that was exceeded only 30 percent of the time. His system was abandoned in 1959 because it failed to adequately distinguish seasonal differences.

Mutch (1958) developed a seasonal severity rating system based on weighted burning indexes for the period of June 1 to September 30. At the time, this system was more acceptable in the Intermountain area and fitted the Intermountain Fire-Danger Rating System better than any other system. Neither Mutch's nor Gisborne's method would indicate severity of the fire season until the season had ended. Later Mutch incorporated Severity Index, a part of the revised Intermountain Fire-Danger Rating System. The Severity Index was based on 5-day running total of 1/2-inch fuel stick moisture readings. Mutch found that by accumulating this index beginning June 1, he could plot a normal curve and then relate any other season to this curve. This method employs only fuel moisture, consequently is less indicative of seasonal severity than his weighted burning index. The major advantage of the changed method was the ability to estimate relative seasonal severity at any time of the season.

Barney (1964) further developed the concept of rating cumulative fuel moisture. Instead of using the calculated Severity Index, he used daily reading from the 1/2-inch fuel stick directly. This eliminated the need for converting data to the Intermountain Fire-Danger Rating System. Barney was able to total daily fuel moisture by 5-day intervals and prepare a cumulative total for the season. Using all past weather records for a station, one could calculate the normal cumulative total by 5-day intervals. For any given year, one could start to cumulate daily fuel moisture. At any specified interval, one could compare the total of the cumulation to the normal and express it as a percent of the normal. This system was also based on fuel moisture only and did not consider other factors that influence seasonal severity.

The Kaniksu fire records were tabulated by size, cause, and time of year. From these data the percentage of fires that exceeded 1/4 acre and 10 acres were graphed by season (fig. 4). As one would expect, the two curves were well separated and looked alike. Low points on these curves indicate periods when the growth rate of fires and hence, seasonal severity, appeared low. High points in the curve indicate periods when growth rate of fires and hence, seasonal severity, were apparently high. The lowest years charted were 1942, 1948, and 1959.

Periods when both curves exceeded their means were 1944-45-46, 1951-52, 1958, and 1960. Considering both curves, with emphasis on the percent of fires that exceeded 10 acres, the highest years were 1945, 1951, and 1958. The year 1949 had the most fires, but rated below the mean in severity. The second highest fire occurrence was in 1944, the third was in 1947. One of the highest apparent severity ratings was in 1958. The 2 years with the lowest fire occurrence were 1948 and 1955. Both years rated very low in severity.

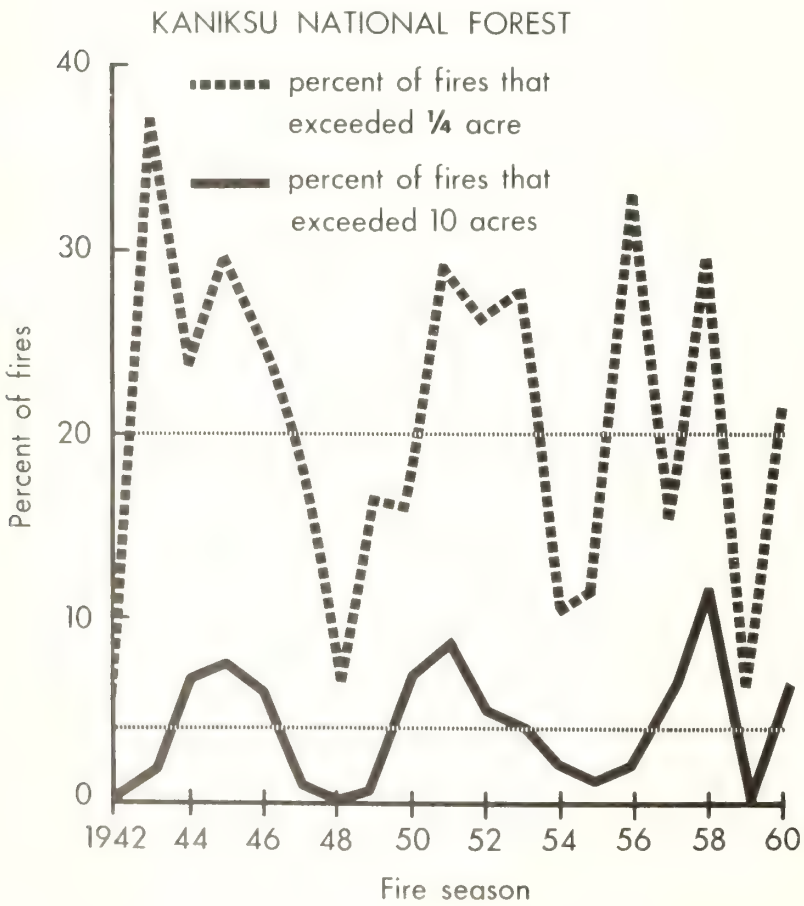
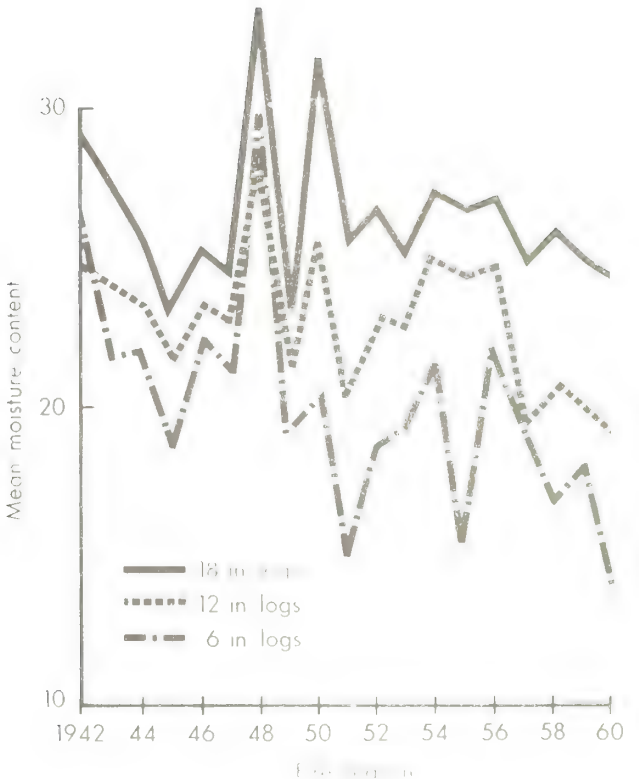


Figure 4.--The percentage of fires that exceed 1/4 acre and 10 acres by season.

Figure 5.--The mean moisture content for each size of logs during the most critical portion of the fire season.



How closely did log moisture correspond to seasonal severity as measured by fire activity? For this comparison, the mean moisture contents for all (6-, 12-, 18-inch) logs were determined and plotted for the critical period of July 1 through September 5 (fig. 5). Because statistical tests indicated that the mean moisture content of 18-inch logs was least correlated to seasonal fire activity, only mean moisture contents of the 6- and 12-inch logs were plotted by percentages of fires that exceeded 1/4 acre and 10 acres. These plottings (fig. 6) reflect very poor correlation.

The other analysis of fire season activity compared log moisture to calculated potential severity of the fire season, not experienced fire activity. None of the seasonal rating systems (Gisborne, Mutch, Barney), when compared to the mean moisture content of logs, gave high correlations. Mutch's Weighted Burning Index System gave fair correlation--probably because the Weighted Burning Indices, like large log moisture measurements, reflect factors other than moisture content of small fuels. Large fuels respond more slowly, therefore integrate and retain more of the total cumulative environmental influences than small fuels. When the Mutch system was compared to the experienced fire season, correlations were as poor as when log moistures were compared to fire season activity.

The second and most important objective of this study was to determine the factors that controlled or influenced the moisture content of large fuels. Results of preliminary statistical tests indicated (as found by Hayes) that precipitation is the major controlling factor. Consequently, all precipitation departures from normal were plotted. Curves were compared to the mean moisture content of logs during the fire season. There was no evidence that the summertime moisture content of logs was dependent upon the previous fall, winter, or early spring precipitation. Apparently, precipitation at the Priest River Experimental Forest is adequate to recharge the water content of logs each winter. The summertime moisture content of large fuels appeared to be more closely related to late spring and summer precipitation than to precipitation during the previous season.

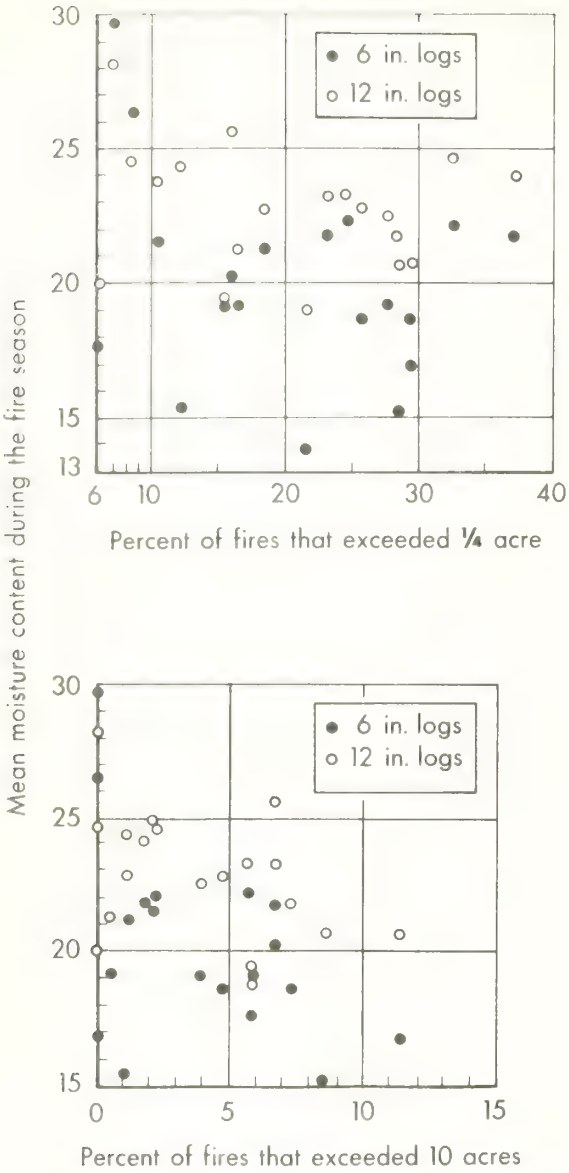


Figure 6.--The mean moisture content of logs plotted against percent of fires that exceeded 1/4 acre and 10 acres.

Variables considered important in determining log moisture were analyzed through an automatic data processing program for stepwise multiple regression with pooled covariance options. A. R. Stage[1] assisted in organizing the data. He programed and ran the analysis. The first step of the analysis consisted of pooling all of the data of the 12 subsets and computing a stepwise regression allowing all of the variables to be selected or removed by the program on the basis of "F" tests.

The next step of the analysis consisted of applying the final model of the stepwise regression to compute a regression for each individual subset. In the final run, all variables were forced on each subset to determine a regression for each subset. Additional machine analyses were directed by Michael A. Marsden of Intermountain Station.

[1] Stage, A. R. 1962. Program for stepwise multiple regression with pooled covariance option. Unpublished report on file at Intermt. For. and Range Exp. Stn., Moscow, Idaho.

Data processing provided average values and standard deviations of all variables in addition to regression equations. The average moisture contents (X_6) are lowest for the logs off the ground in the clearcut exposure. Logs in the clearcut on the ground are next, followed by logs in the full-timber on the rack and logs in the full-timber on the ground. The fluctuations of moisture content--the responsiveness of the logs to change--are evident in the standard deviations of Y. For each of the four exposures, 6-inch logs have the highest deviation in gain or loss, followed by 12- and 18-inch logs, respectively.

The first part of the stepwise regression analysis was made with the pooled data. The first variable chosen by the program was X_8 (the amount of precipitation). Step 2 included X_6 (the moisture content of the logs at the beginning of the observation period). The addition of X_6 more than doubled the coefficient of determination and reduced the standard error of Y from 4.189 to 3.390. Variables X_9 (mean temperature) and X_7 (number of hours of precipitation) were added in that order. Further steps of regression produced almost undetectable improvements in the equation. At this point the equation read:

$$Y = K - [0.36 \pm t(0.0078)]\, X_6 + [0.29 \pm t(0.046)]\, X_7 + [2.90 \pm t(0.12)]\, X_8 - [0.51 \pm t(0.0077)]\, X_9$$

where K is a subset constant.

K values for the regression equation are:

Clearcut rack	K values	Full-timber rack	K values
6-inch	7.49	6-inch	9.90
12-inch	7.61	12-inch	9.61
18-inch	10.10	18-inch	10.93
Clearcut ground	**K values**	**Full-timber ground**	**K values**
6-inch	9.01	6-inch	10.88
12-inch	9.26	12-inch	10.58
18-inch	9.74	18-inch	11.49

Beta coefficients are: $X_6 = -0.55$: $X_7 = +0.12$: $X_8 = +0.48$: $X_9 = -0.86$. Standard error of Y = 3.338. Coefficient of determination = 0.505.

Stepwise regression was continued to completion. Variables were added. Some were removed. The final standard error of Y equaled 3.330, an insignificant improvement. Likewise, the final coefficient of determination was only 0.508.

The final pooled equation was used as a model to compute a regression equation for each subset.

An "F" test was made to determine whether the separate regression coefficients differed significantly from the pooled regression with the appropriate constants. This test for parallelism revealed no significant difference.

The pooled regression equation with the corresponding subset K values was used to predict log moisture curves for each of the 19 study years and compared to the measured data. The same equations were used to predict moisture curves for 1967 and 1972. North Idaho was noted for having a very severe fire season in 1967; whereas 1972 was a very easy year with little fire activity. The lowest moisture curves predicted by these equations for the 19-year study period and the 2 additional test years appeared in the late summer of 1967 at the time of the Sundance and other large fires in north Idaho (fig. 7).

According to the equations, 1943 was a very dry season, but the low log moisture occurred very late in the year. In 1949, the season started out with low log moisture but turned upward quite early. The year 1951 was initially dry but had an early recovery beginning August 25. The year 1952 was similar to 1967. However, the very dry period in 1952 started later than in 1967 and did not quite hit the same low, although recovery was later in the fall. The year 1958 was also very similar to 1967 in both the early and late season but did not have the deep trough in midsummer. The 1972 prediction curves were not unusual, as there were other comparable years during the 19-year study period.

The prediction curves were started at the 19-year mean for beginning moisture content for each subset. Results indicated that large log fuels recharged every winter from rain and snow. However, late spring drying prior to initiation of moisture measurements produced large differences of beginning moisture content on May 1.

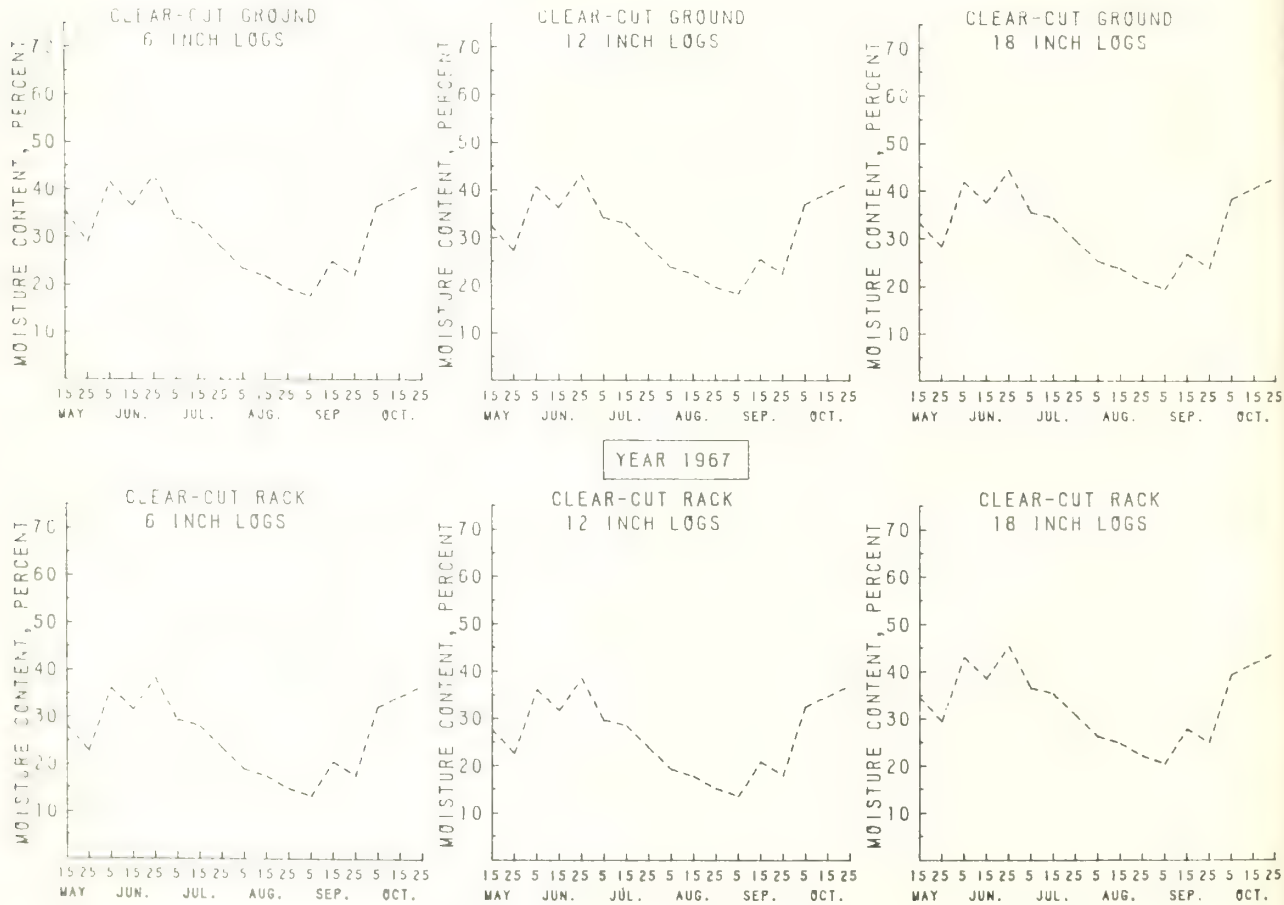


Figure 7.--Predicted moisture content of large fuels at the Priest River Experimental Forest for 1967.

To be most useful, prediction equation [illegible] benefit of large fuel samples exposed to the environment. It was assumed that when using a prediction equation, one would start the [illegible] moisture value.

Tests were made using the prediction equations following an observed beginning moisture content. In these cases the curves of predicted and measured values were somewhat closer.

All of the statistical proofs applied against the equations appeared weak. They do not indicate that the prediction curves are reliable, responsive, or sensitive. Yet, the predicted curves did follow the Priest River measured data curves for all 19 years and for the few years at Boise Basin. Although it appears the correct factors were used for predicting gain or loss of moisture, they were not adequately responsive for making precise distinctions or for making difficult management decisions.

The data suggest that logs actually dry more than the equations predict. Once the season starts, measured moisture is nearly always lower than predicted. This discrepancy may be because of drying factors such as wind or accumulated differences resulting from night-time recovery, which will change as the length of night and moisture deposition varies.

Moisture contents of white pine and cedar logs were compared for the overlap period 1942-43. The moisture curves for the two species nearly paralleled each other in all cases. The moisture content of the 6-inch 1939 white pine log paralleled that of 6-inch cedar logs for both 1942 and 1943 but was significantly less throughout both seasons. The moisture content of 12-inch 1936 and 1939 white pine logs also paralleled that of the 12-inch cedar. The cedar most nearly matched that of the 1939 log in moisture content but was slightly higher in moisture content throughout the season. The moisture content in the 12-inch cedar was significantly lower than in the 1936 log throughout both seasons. The 18-inch cedars were significantly lower in moisture content than both the 18-inch 1936 white pine and the 20-inch 1939 white pine.

DISCUSSION

This study confirms and extends Hayes' conclusions of 1940 (presented in the introduction). This study, like the previous one, does not provide a reliable index of seasonal, monthly, or current fire-danger severity. Other methods using Weighted Burning Index Severity are superior because they are easier to use, are more sensitive, and consider factors other than moisture.

Large fuels at the Priest River Experimental Forest normally dry out rather quickly through May and into June. The June rains cause the moisture content to rebound upward to a peak about the middle of June. Then the moisture content declines sharply in late June and July to a seasonal low in mid-August. The gradual recharge of moisture in heavy fuels takes place in late August and September accelerating through October. See the 19-year average moisture content curves, figures 8 and 9.

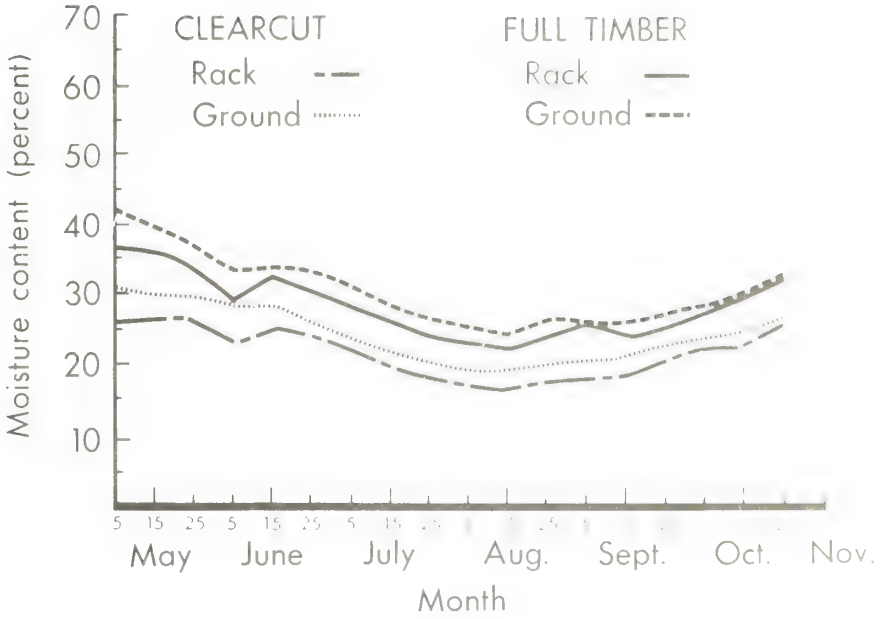
The moisture content added by rain in June probably is confined to the surface and relatively shallow depths because there is hardly time for deep penetration. The drying weather of late June and July would cause rapid loss of this shallow water and then continue to remove the pre-June rain moisture.

A moisture wave from the early June rains probably continues into the inner layer of the fuel but is overshadowed by the drying influence of the long, dry summer season. By mid-August the gain and loss are near a balance and then the recharging begins. At Priest River, fall, winter, and spring moisture recharge in large fuels is sufficient to render seasonal moisture carryover insignificant.

Late spring weather and fire season weather largely control the moisture content of large fuels during the fire season. Average moisture content of large fuels during the fire season does not seem to vary greatly from year to year. This may be because the center of heavy fuels is more or less inert to change. The drying season may not be long enough to affect the center of heavy fuels. The average moisture content of a specified depth of large fuels might well be a better measurement of dryness, or the gain or loss of moisture in this portion of the fuel might be more easily accounted for by weather factors.

Using the average moisture content of whole logs, only about half of the gain or loss of moisture was accounted for by regression analysis. Results indicate that precipitation and the moisture content of the logs at the beginning of each observation period control much of the accountable gain or loss of moisture. Hours and amount of precipitation and mean temperature were selected by the regression analysis as having some bearing on the gain or loss of moisture in large fuels.

Figure 5.--Winter-year storage temperature and moisture content at age thirty-four (Priest River Experimental Forest).



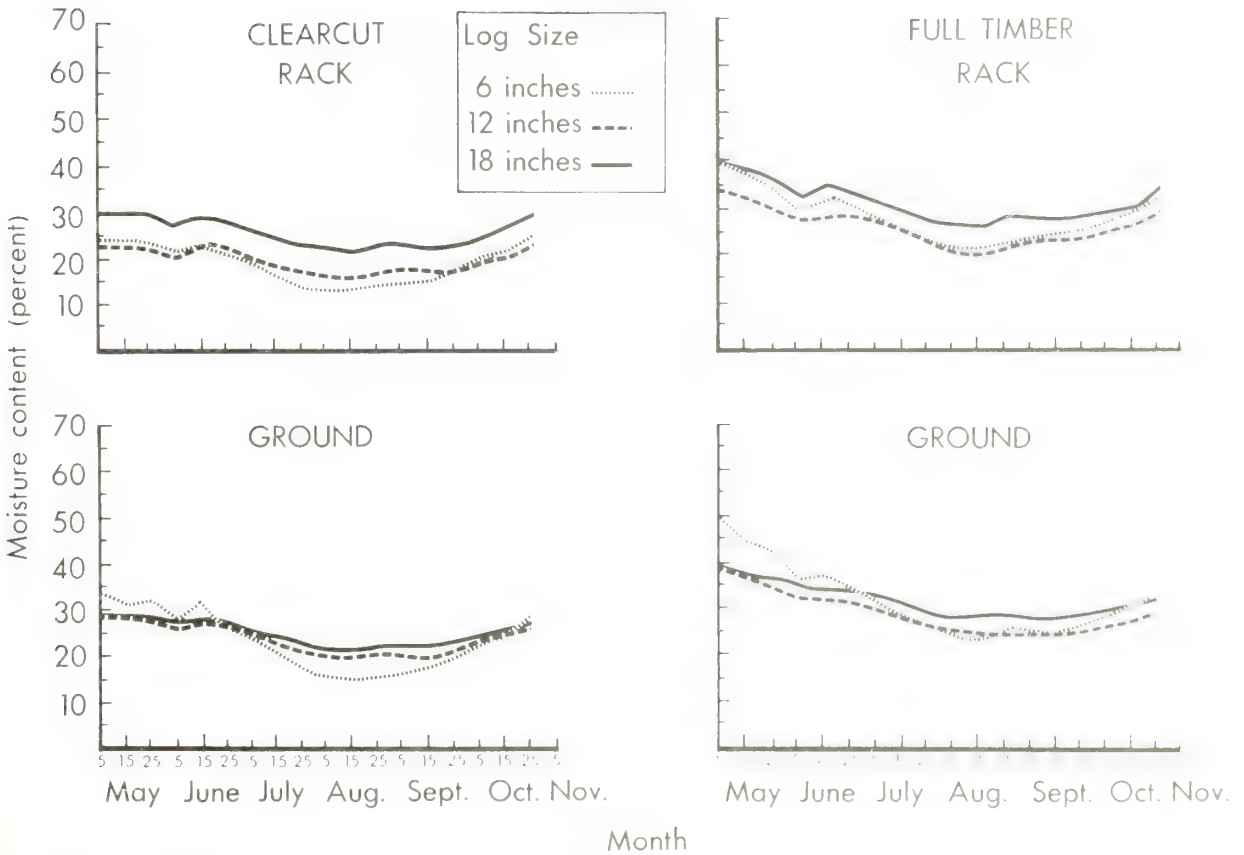


Figure 6.--Winter-year storage temperature and moisture content at age thirty-four (Priest River Experimental Forest).

As one would expect, the better ventilated, more openly exposed logs became drier than the other logs. The logs up on racks out in the clearcut exposure were driest throughout the season.

Nearly all logs checked badly during dry weather. Precipitation tended to collect in the checks on the top and upper sides of the logs. Moisture absorption was influenced by the degree of checking and the location of the checks.

White pine and cedar logs displayed similar response to seasonal weather factors. The moisture content curves of these two species were nearly parallel but always significantly different. Some of the white pine logs ran significantly higher; others ran lower. White pine seemed to be more variable than cedar; however, the white pine selection was not as carefully controlled as the cedar. Cedar might show a greater variability when selected more randomly.

Not enough data were collected at the Boise Basin Experimental Forest to warrant many conclusions. The data indicate that logs placed at Boise in the fall of 1957 carried a higher moisture content than would have been normal for Boise. The first drying season brought rapid weight loss. The logs became much drier than for any year at Priest River. The moisture curves for the second season (1959) were very flat. Either the recharge is not high at Boise, or the early drying occurred before measurements were made. Recharge turned sharply upward late in 1959, but records did not exceed 30 percent moisture content at the end of the study season. The log moisture curves came into the 1960 season low and flat again, as in 1959. The moisture curves did not fluctuate much at Boise during the fire season. They were low and flat for all three seasons. These curves are shown in appendix B.

The lowest log moisture measured at Priest River throughout the study occurred in 6-inch logs in 1960. (The Priest River logs were also very dry at the end of the 1952 season.) The moisture contents of the three sizes of logs at Boise moved closer together each year until they were very close in 1960. Logs continued to dry until the last observation on October 5, 1960, when the lowest moisture for 18-inch logs was recorded.

The large-fuel study did not produce a precise method for predicting fire season or fire activity, nor predicting the exact moisture content of large logs. Nevertheless, seasonal trends of moisture content of large fuels, moisture differences because of cover and ground exposure, and the correlation of log moisture to major weather factors such as precipitation warrant serious consideration in fire planning. The data do indicate that periods of extremely low moisture content are not always associated with great fire activity, a fact confirmed by experience.

Severity of the fire season is difficult to define or measure. Potential severity and experienced severity are not always the same. One might expect more fires and larger fires in a dry season, but they often do not occur. More lightning fires may be started in a moderately dry year than in an extremely dry year. On the other hand, if there are no fires during a very dry period, no data on fire growth are available to express the seasonal fire severity. When burning conditions appear to be less severe, people are more apt to initiate debris burning, land clearing, and right-of-way fires. Loss of control of several of these fires may boost the acreage burned per fire simply because of lack of firefighting readiness. A major weakness in describing seasonal severity by the criteria of actual fire records is the changing influence of man himself. Both risk and efficiency of fire control are constantly changing. Over such a long period as 1942 to 1960 many changes became quite significant. Some changes that influenced risk on the Kaniksu Forest during the study period were:

1. Conversion from steam locomotives to diesel.

2. Construction of access roads to previously inaccessible areas.
3. Changes in logging practices such as conversion from hand saws to chain saws and other power equipment.
4. Increased population.
5. Increased recreational use of the forests.
6. Intensified fire prevention effort by firefighting agencies.
7. Danger of Japanese incendiary bombs during World War II.
8. Occasional arsonists.

Efficiency of fire control has varied too because of new developments or changes of policy. Several important changes have been:

1. Availability and widespread use of the modern bulldozer.
2. Availability of more access roads.
3. Adoption, improvement, and expansion of aerial attack systems.
4. Use of chemical retardants.
5. Improvements in the detection systems.
6. More intensive land management.

These early field studies over long periods of time have contributed to development of fire-danger rating systems and have also taught us about climatic patterns and trends. However, it is questionable that similar long-term studies should be conducted at the present time. There are more efficient, economical ways to arrive at results using more controlled conditions. Gain or loss of moisture in large fuels can be studied more precisely in controlled environment chambers. Although a few controlled-environment studies have been conducted, many more ought to be considered.

PUBLICATIONS CITED

Barney, Richard J.
1964. Fuel moisture, a guide for evaluating severity of fire season. U.S. For. Serv. Res. Note INT-13, 8 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Byram, G. M., and G. M. Jemison.
1943. Solar radiation and forest fuel moisture. J. Agric. Res. 67:149-176.

Hayes, G. L.
1940. The moisture content of large sized fuels as an index of intraseasonal and seasonal fire danger severity. M.S. thesis submitted in partial fulfillment of the requirements for the degree of M.S. For., Sch. For., Yale Univ.

Jenkins, J. H.
[n.d.] The seasoning of Douglas-fir timbers and western redcedar poles. For. Prod. Lab. of Can., Ottawa.

Mutch, Robert W.
1958. A system for rating seasonal forest fire severity. Master's thesis presented in partial fulfillment of the requirements for the degree of M.S., Mont. State Univ. 48 p.

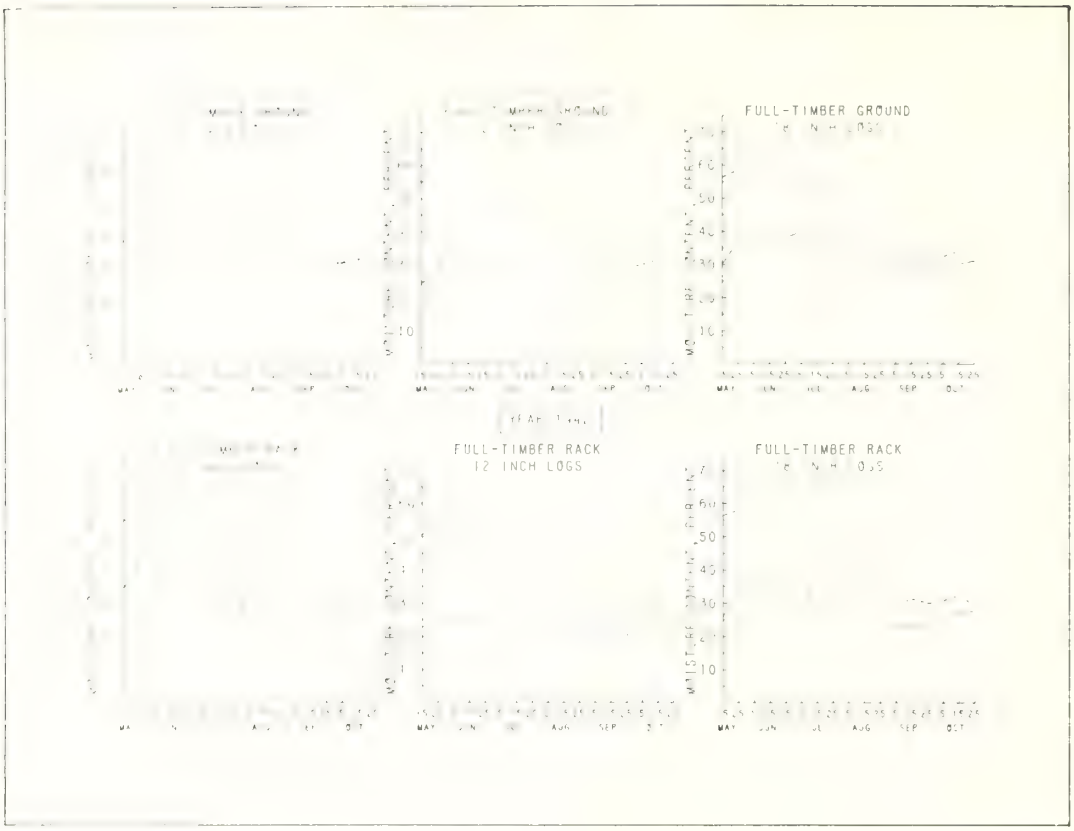
APPENDIX A

Large fuel moisture content curves are plotted for measured data and by a prediction equation. All exposures for the 19-year study period and for 1967 and 1972 are plotted for the work at Priest River Experimental Forest.

Legend:

_____ Measured Data

---------- Predicted Values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FULL-TIMBER RACK
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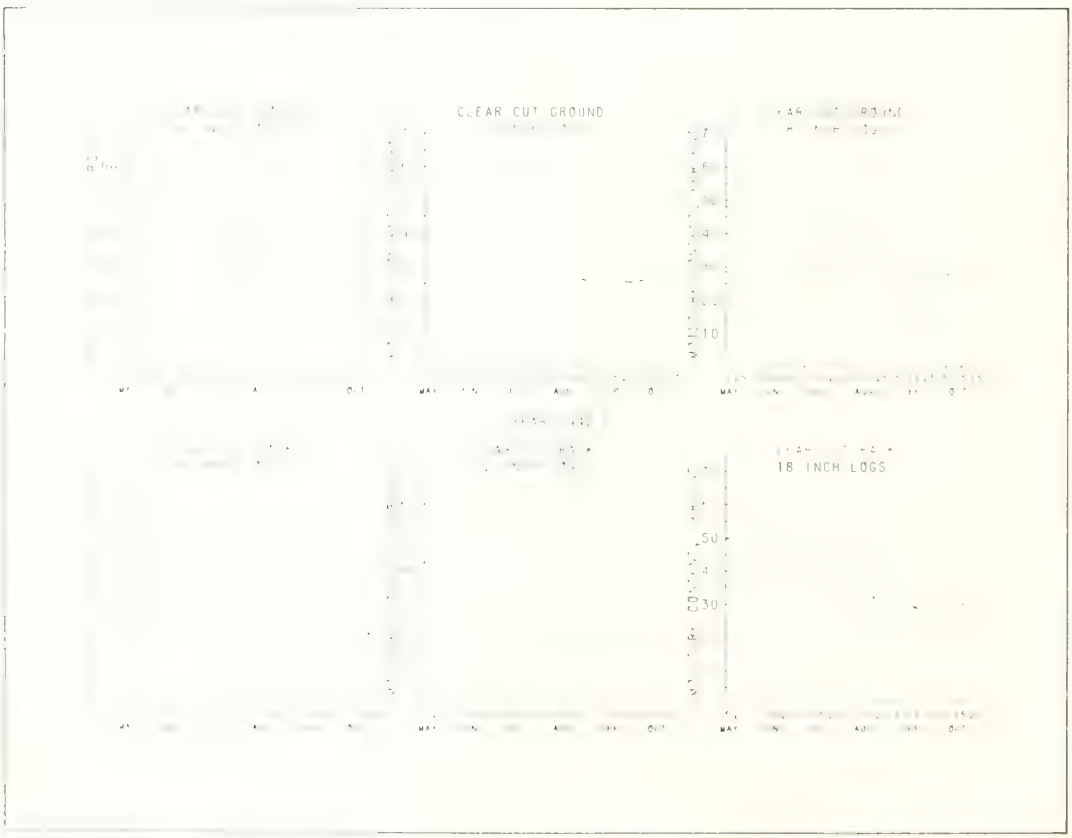
FULL-TIMBER RACK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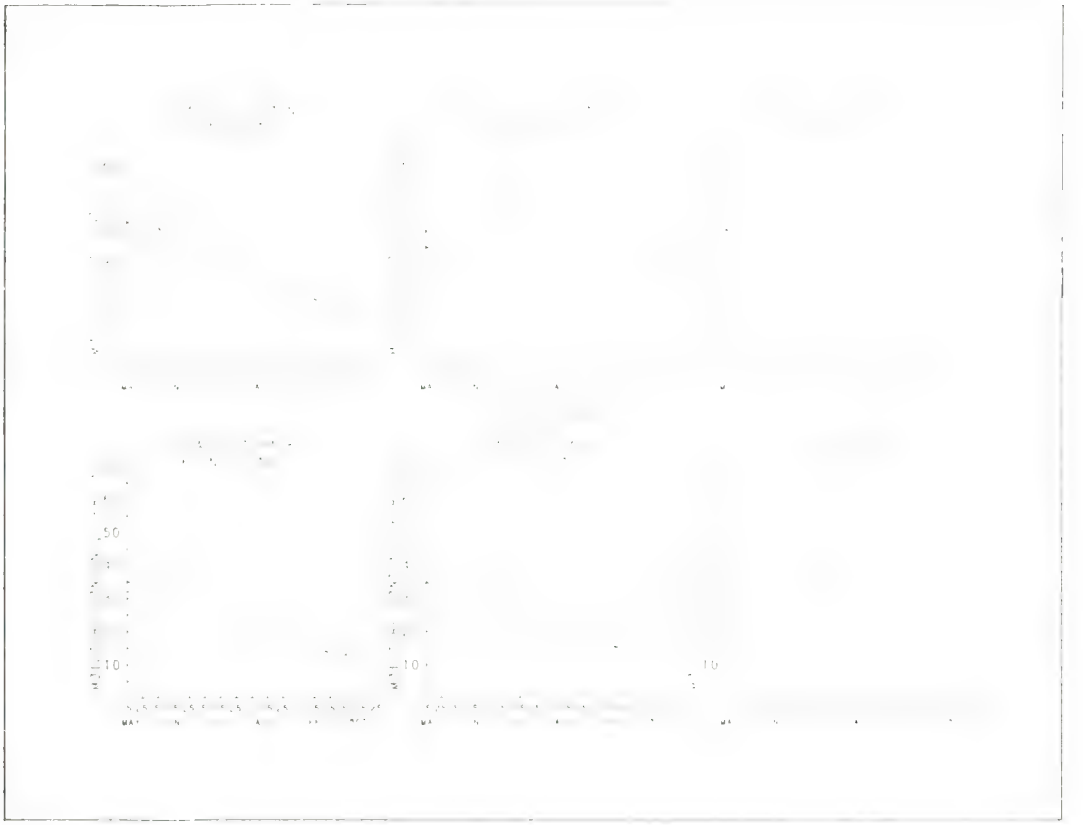
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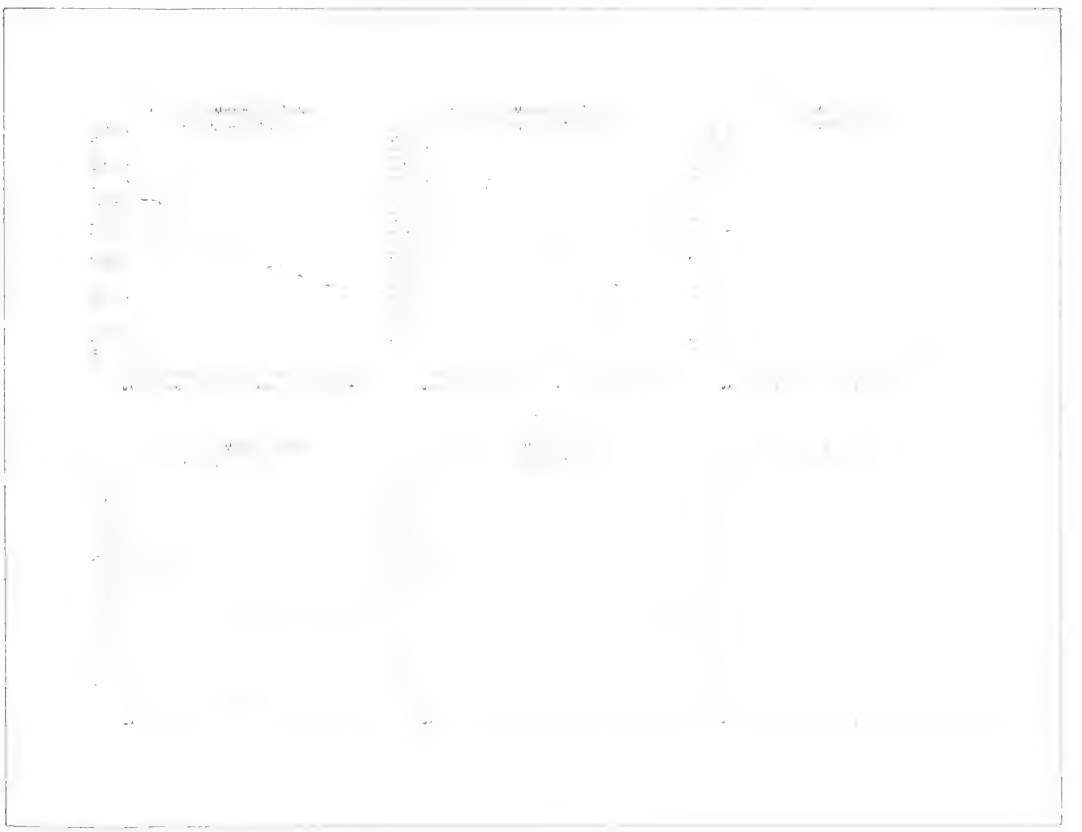

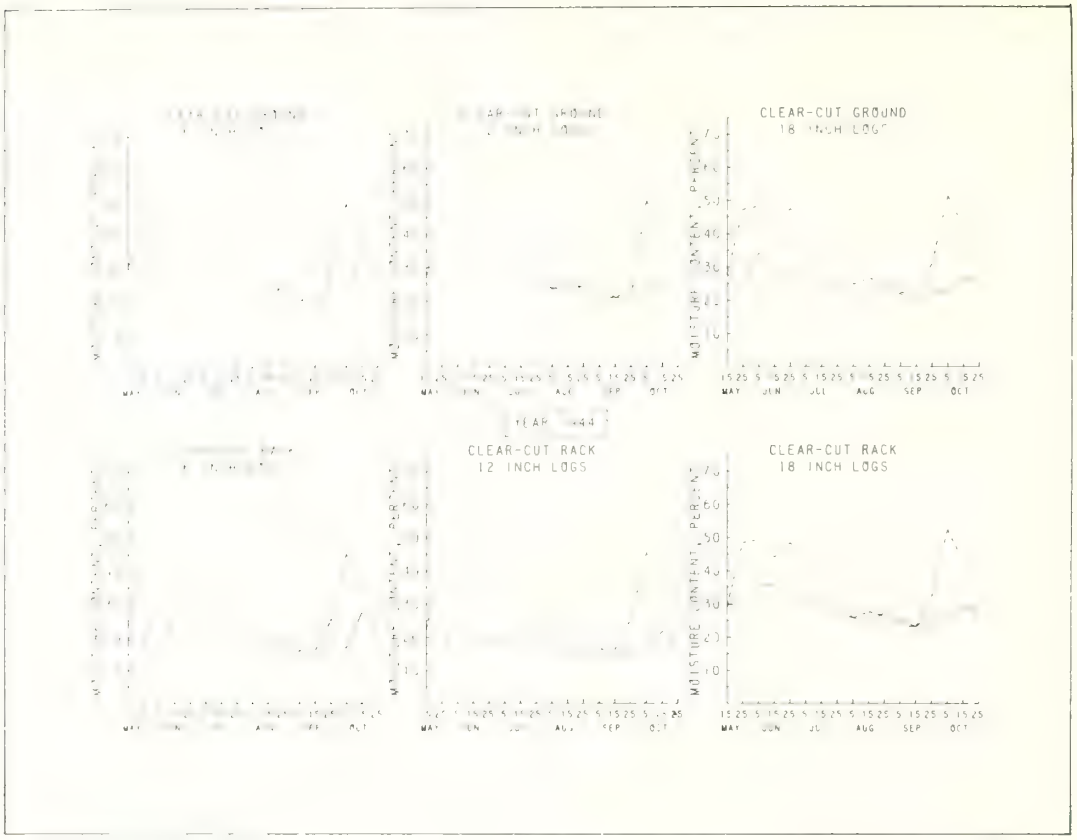
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YEAR 944
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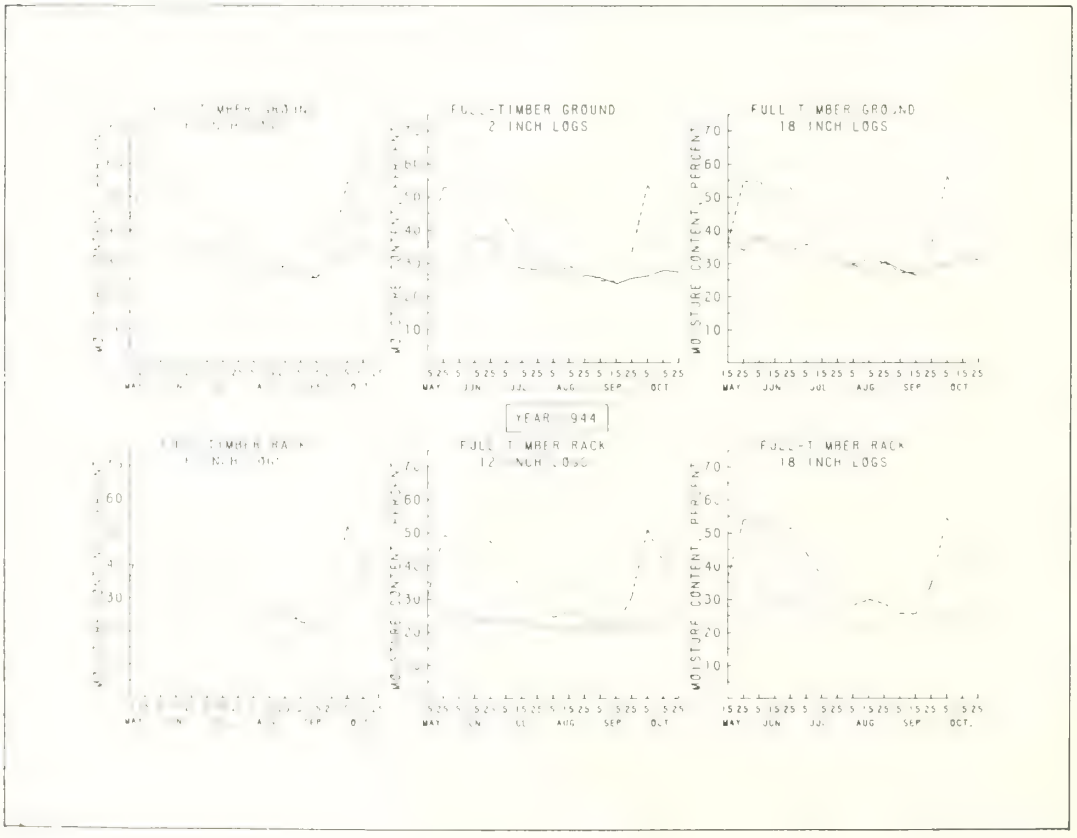
18 INCH LOGS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YEAR 944
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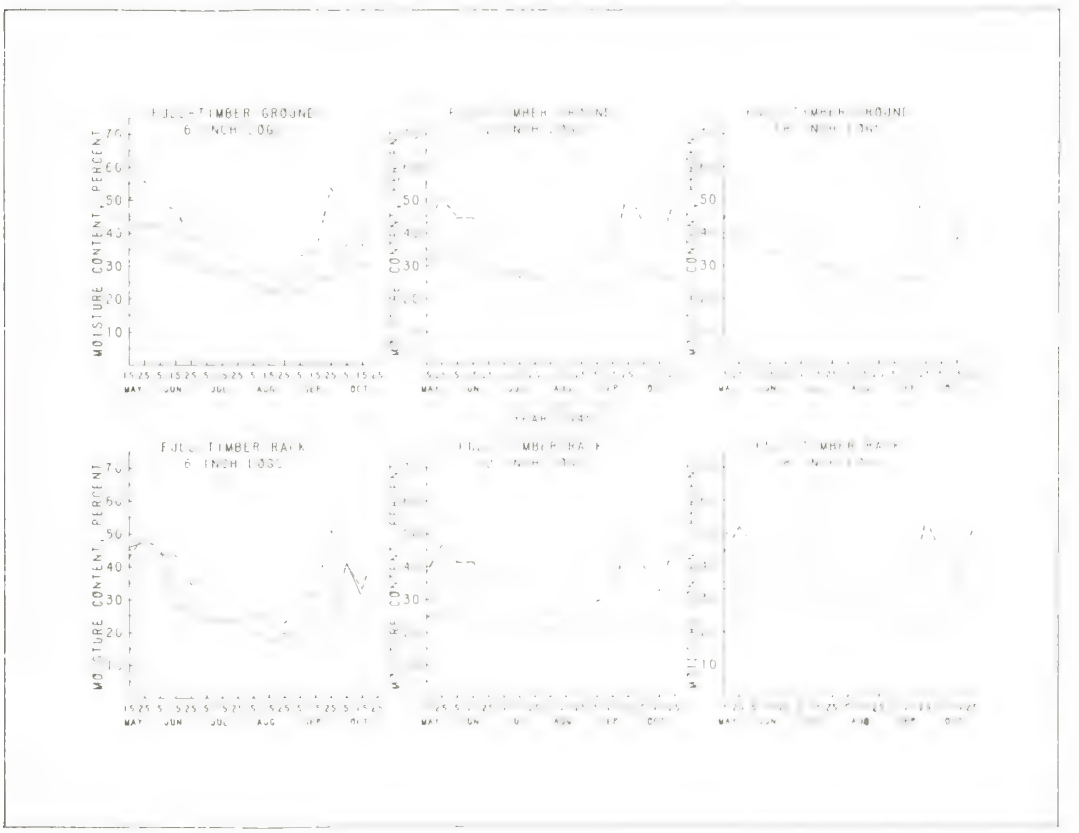
CLEAR-CUT RACK
MOISTURE CONTENT, PER
MAY JUN JUL AUG SEP OCT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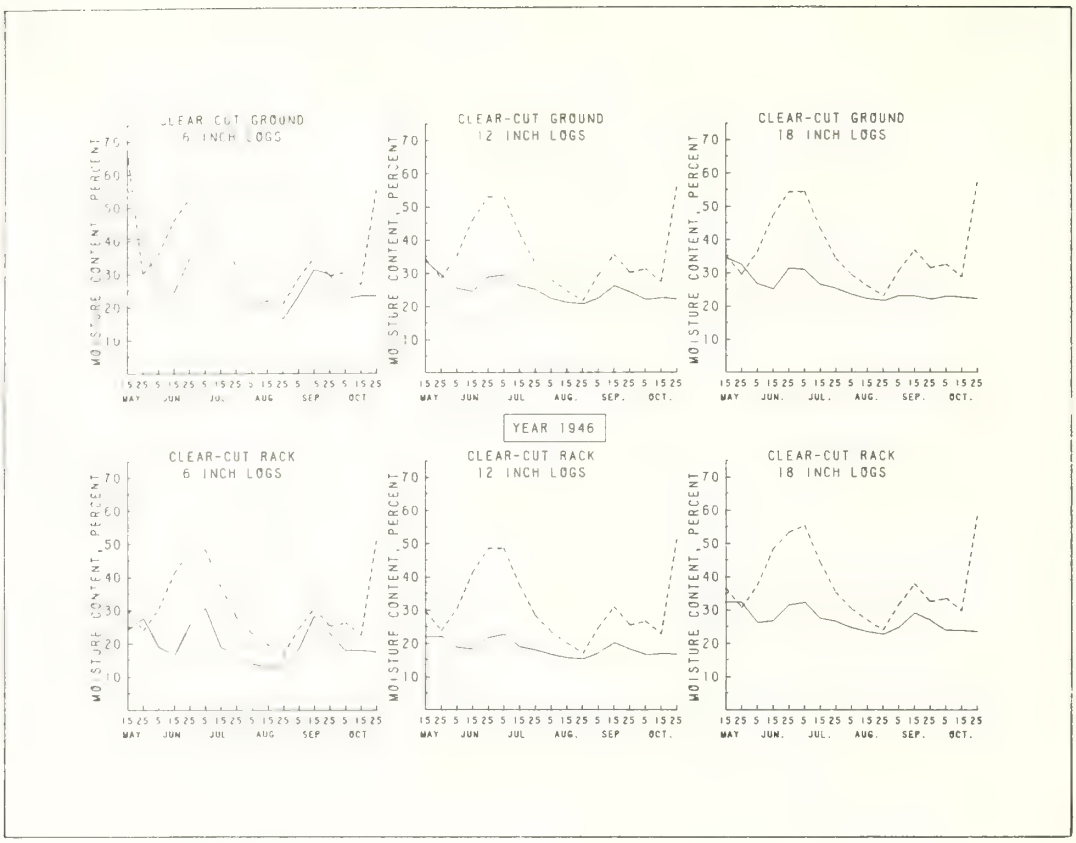
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MOISTURE CONTENT, PERCENT
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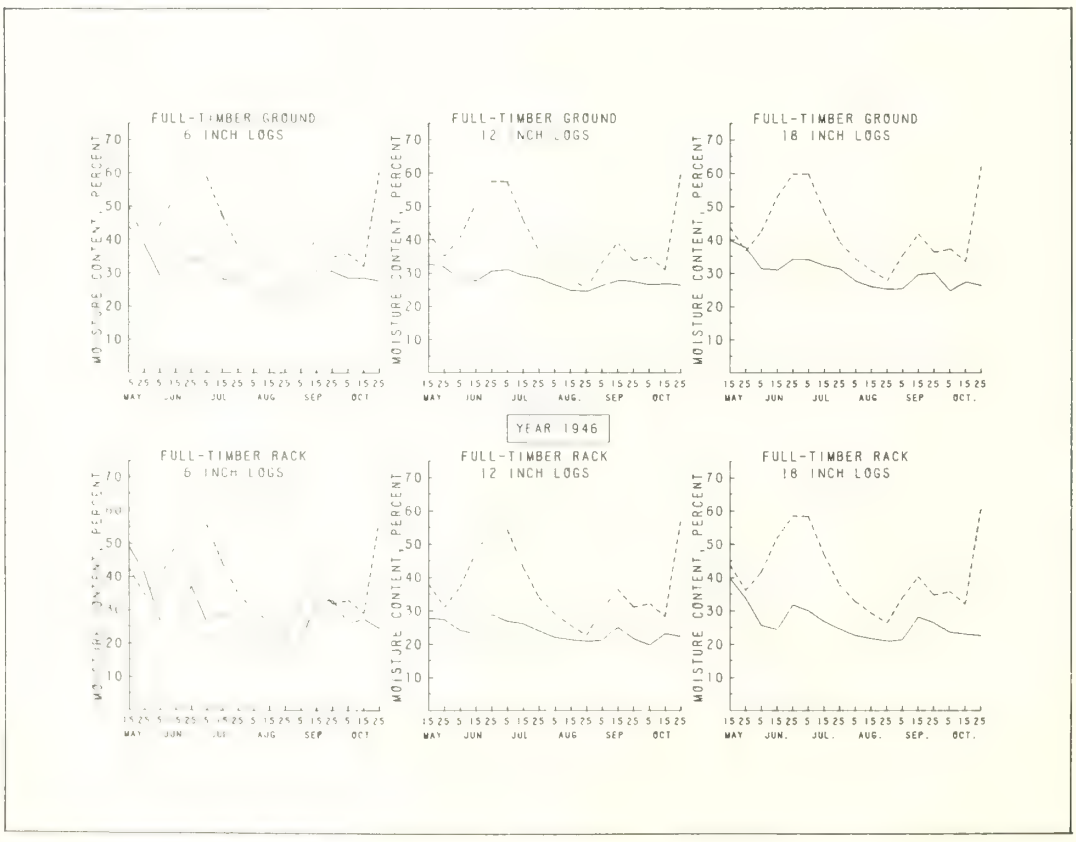
18 INCH LOGS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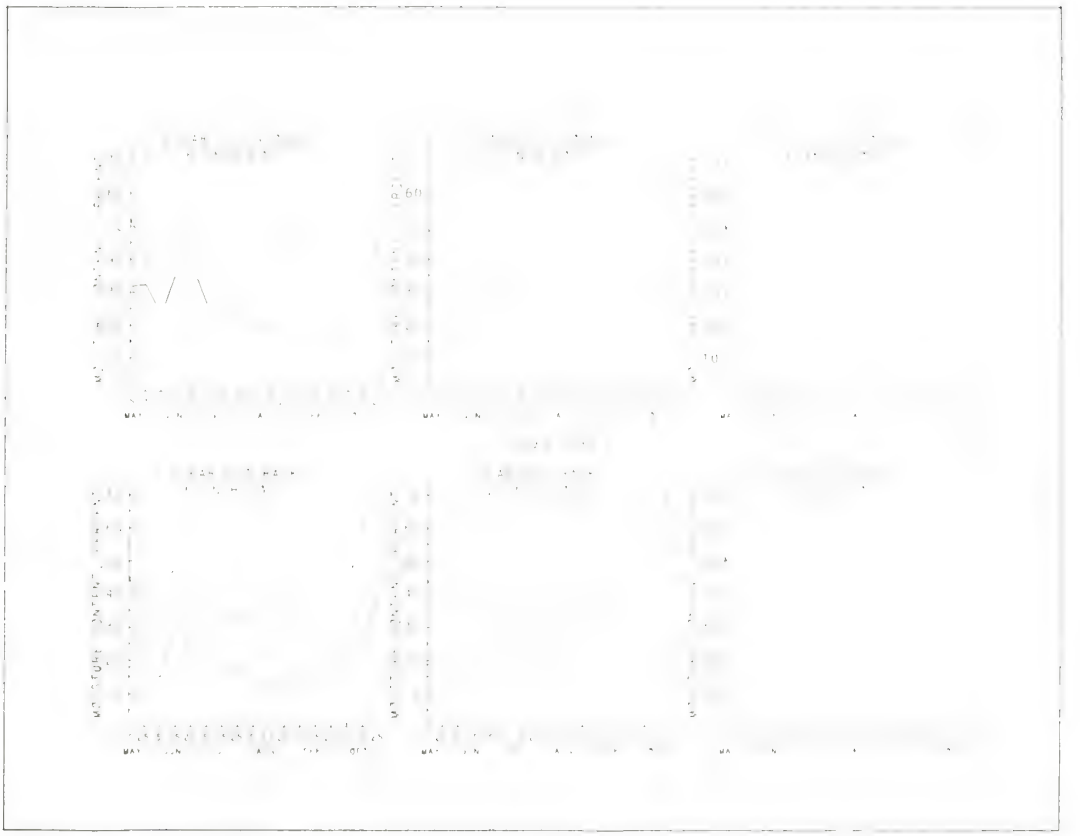

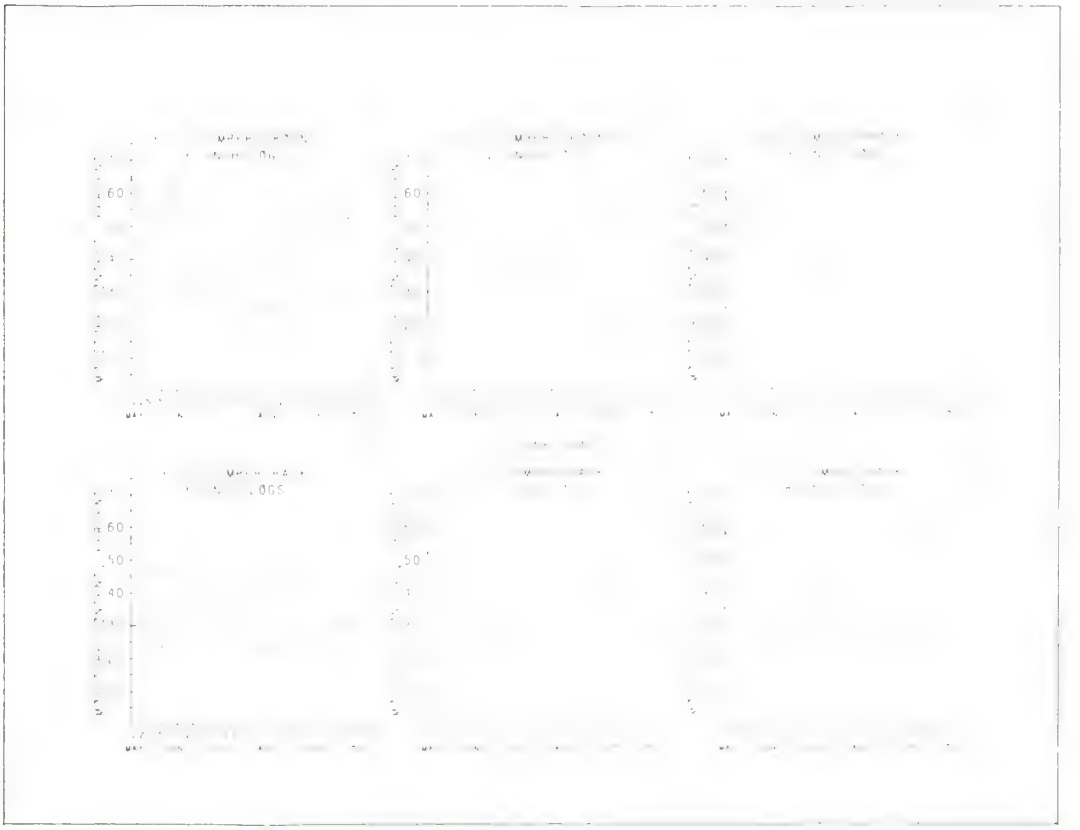

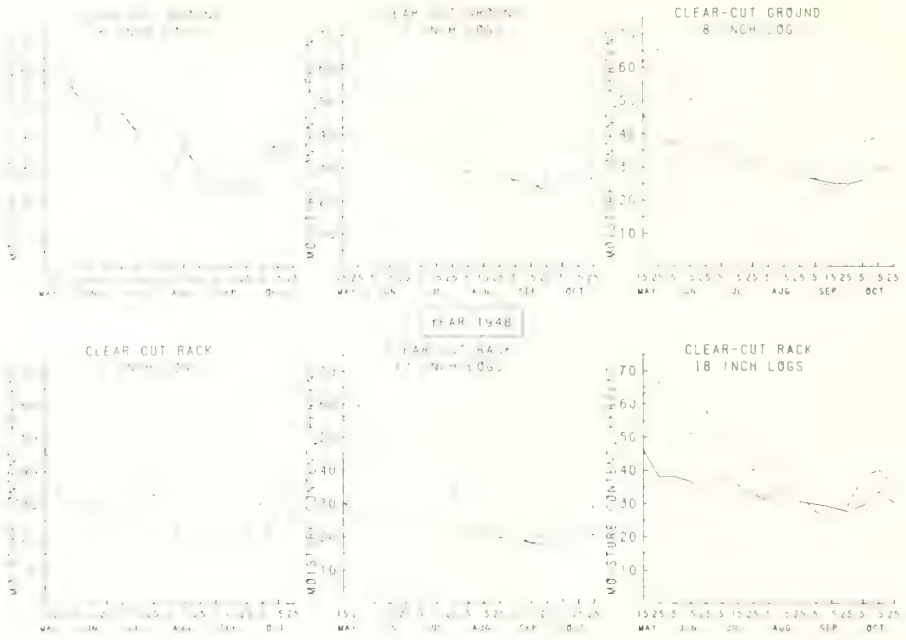
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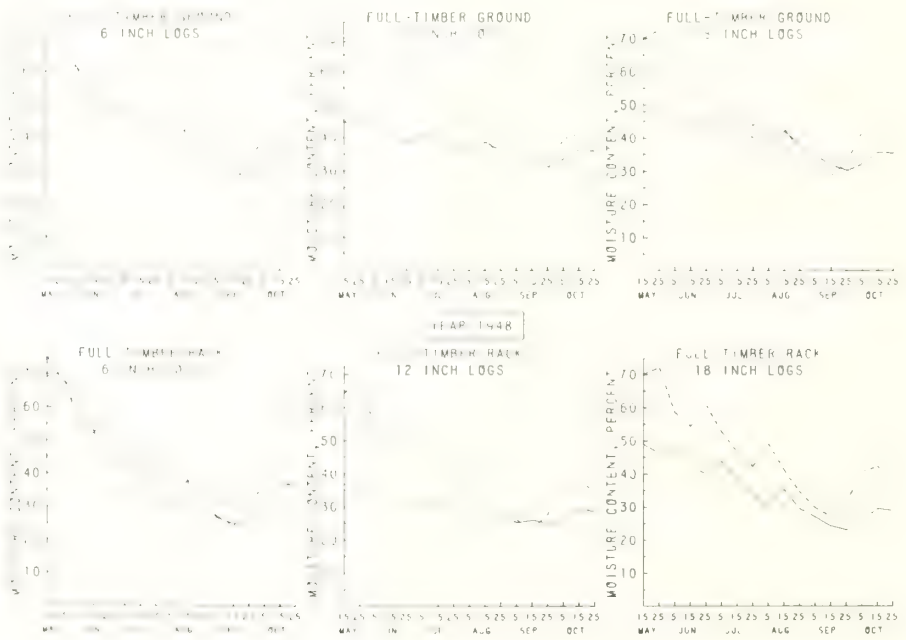
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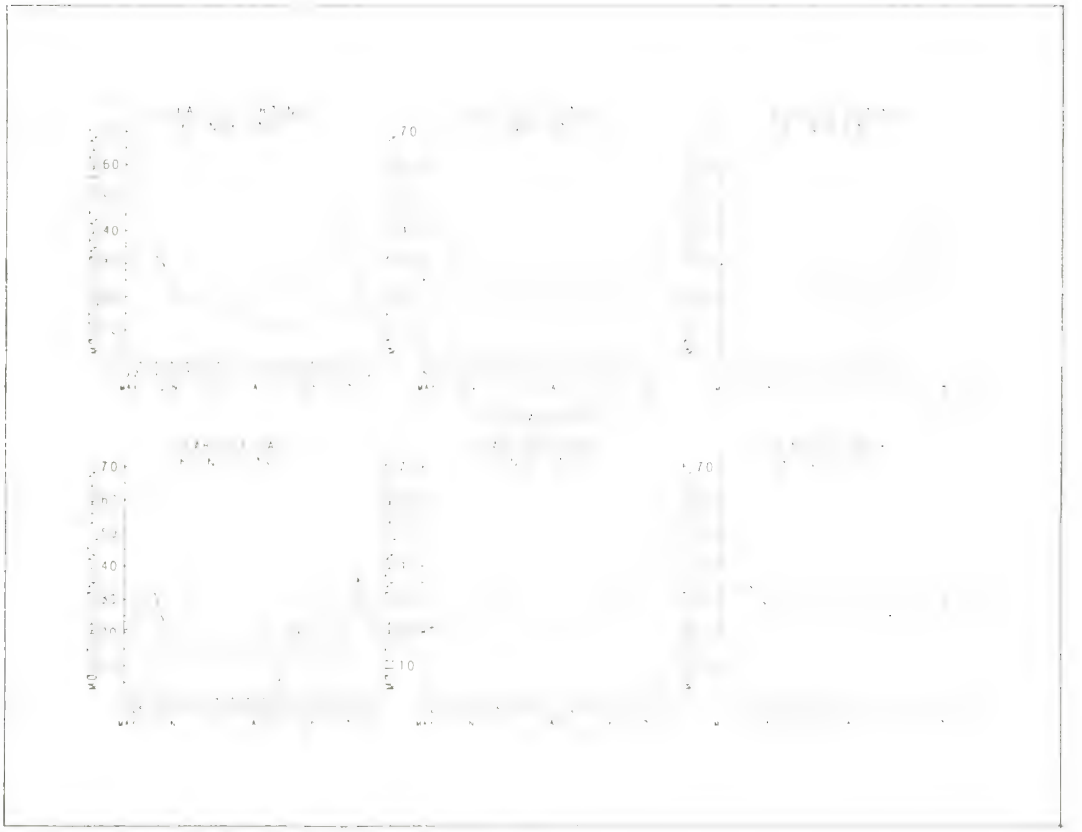

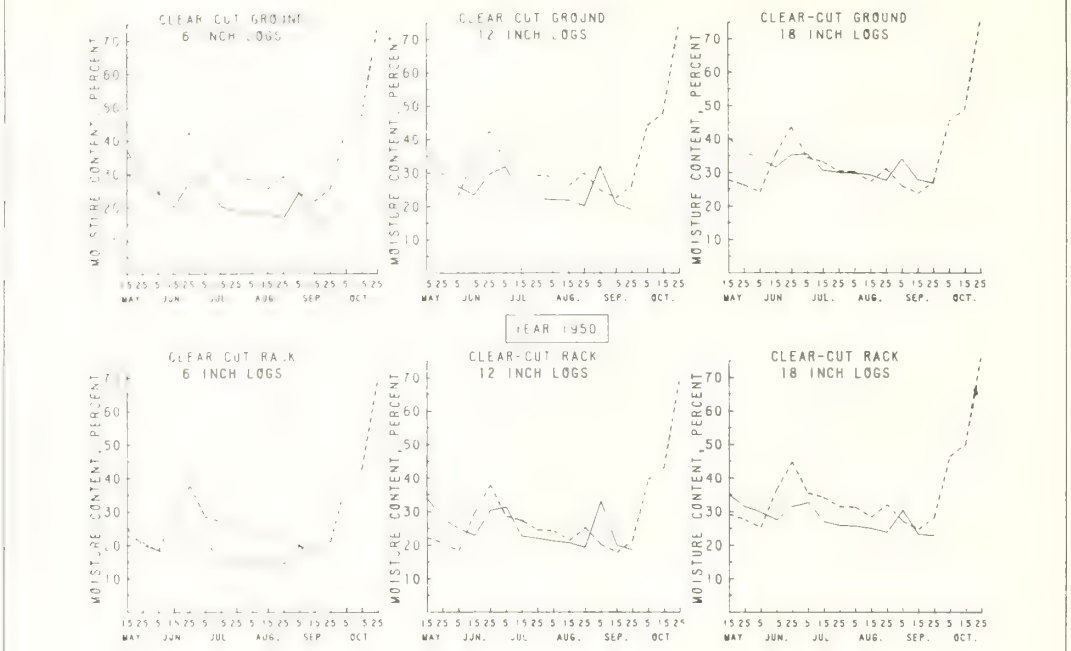
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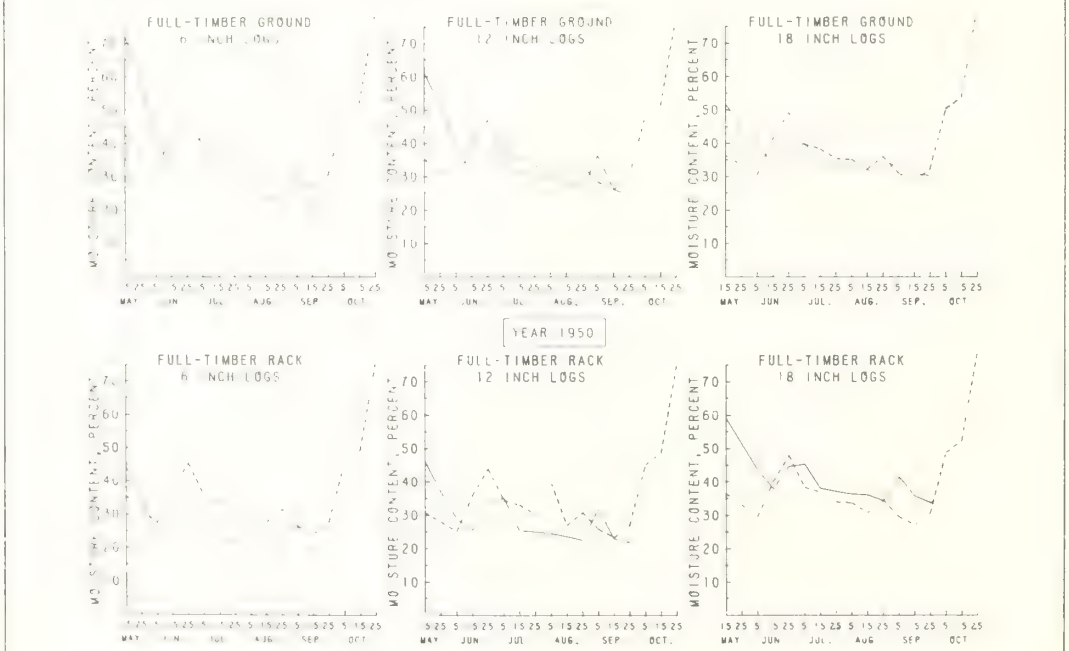
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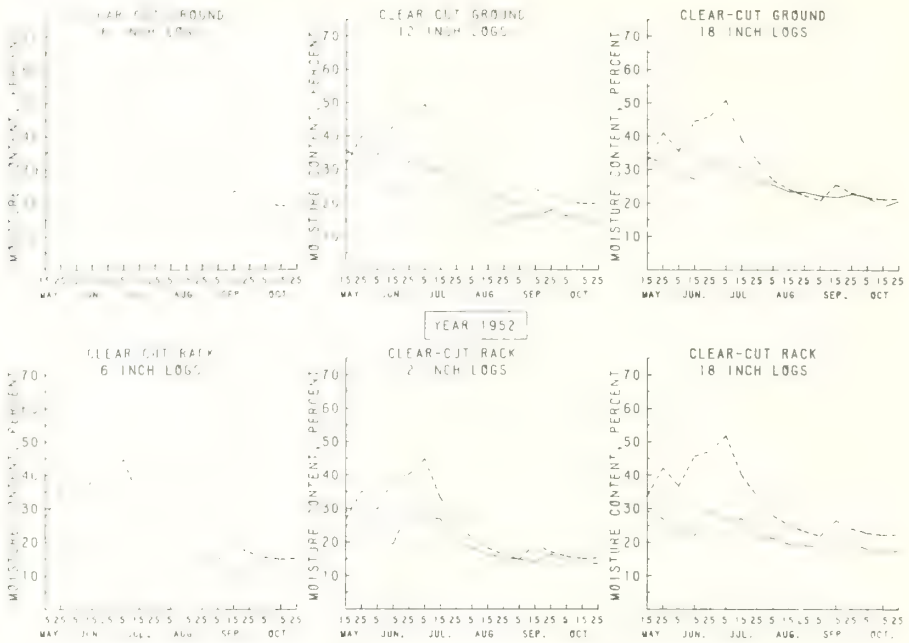
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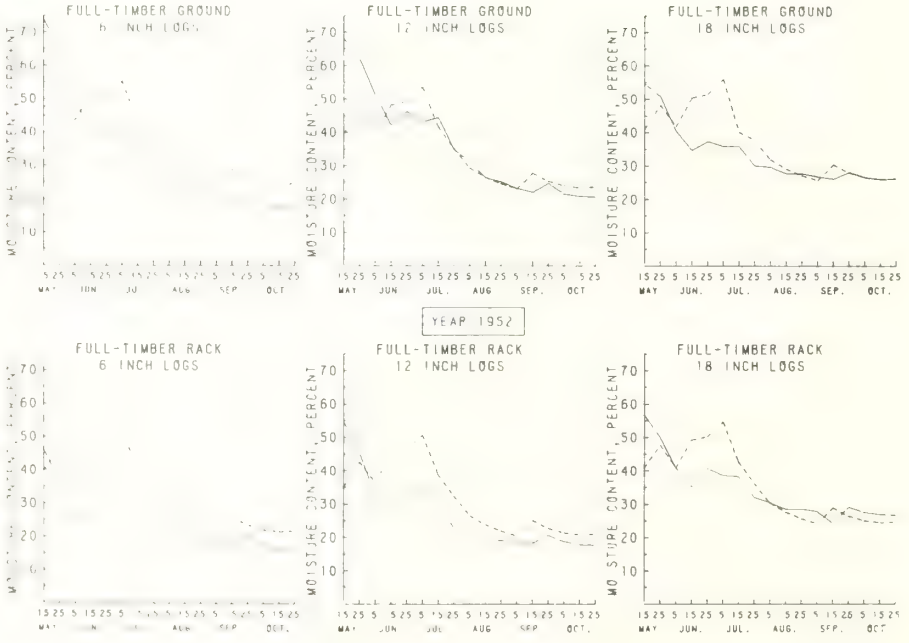
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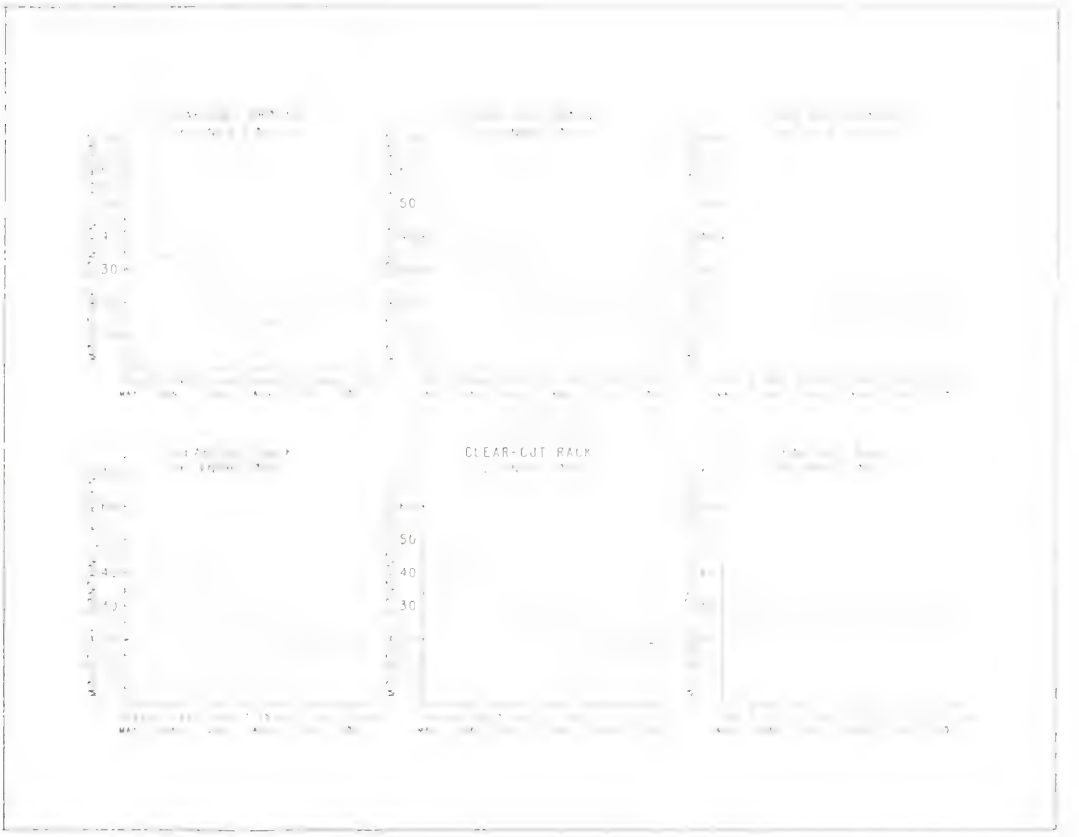
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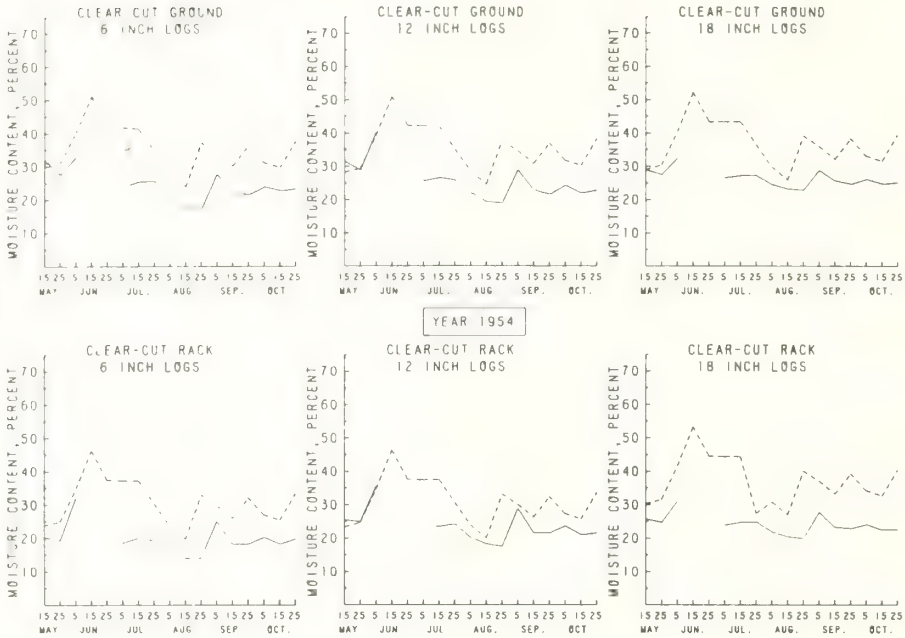
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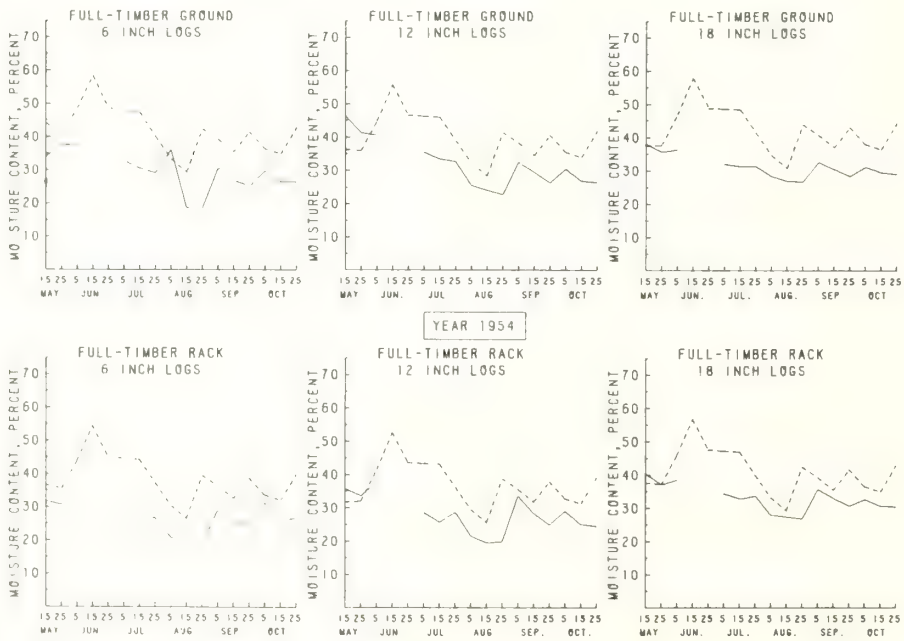
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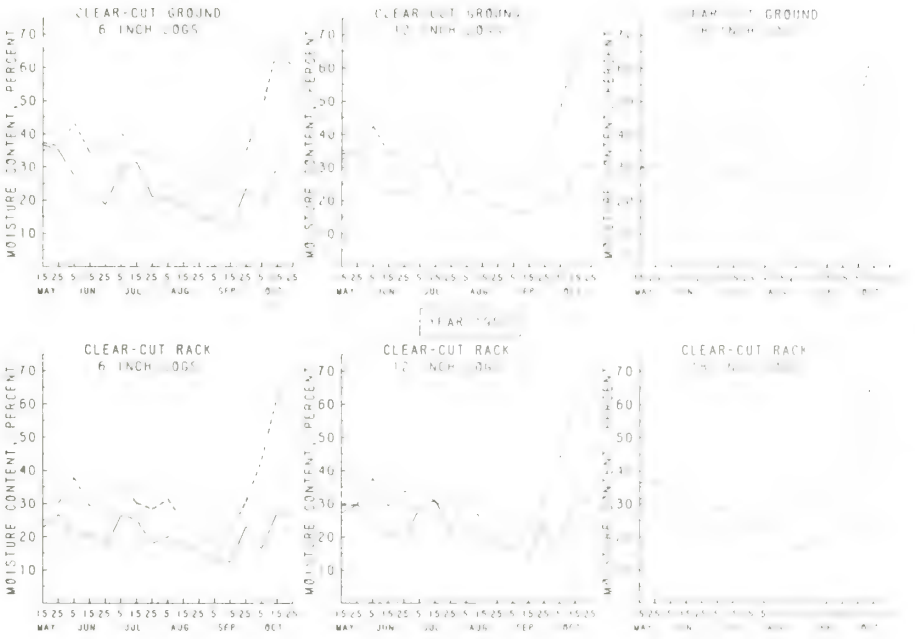
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MOISTURE CONTENT, PERCENT
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SEP
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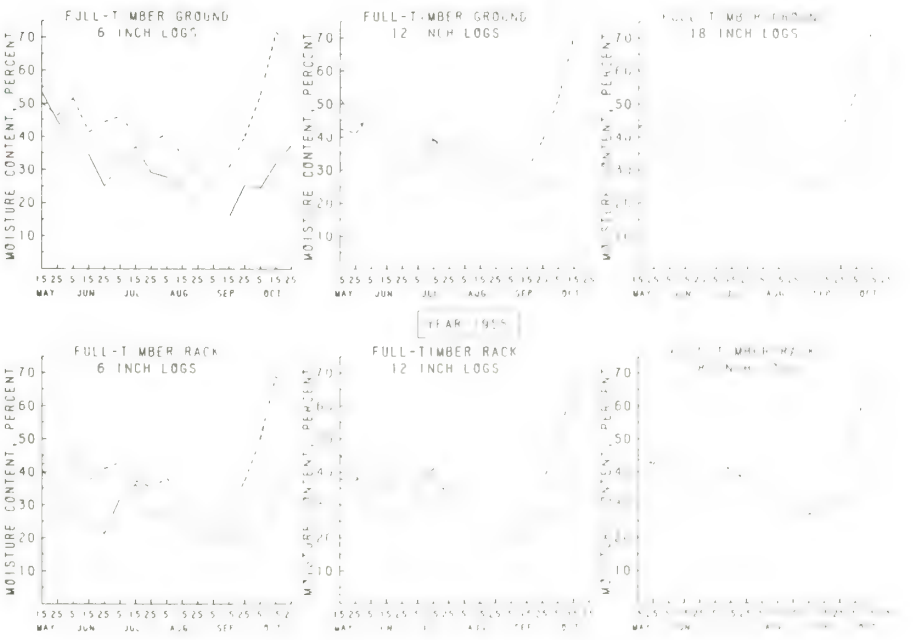
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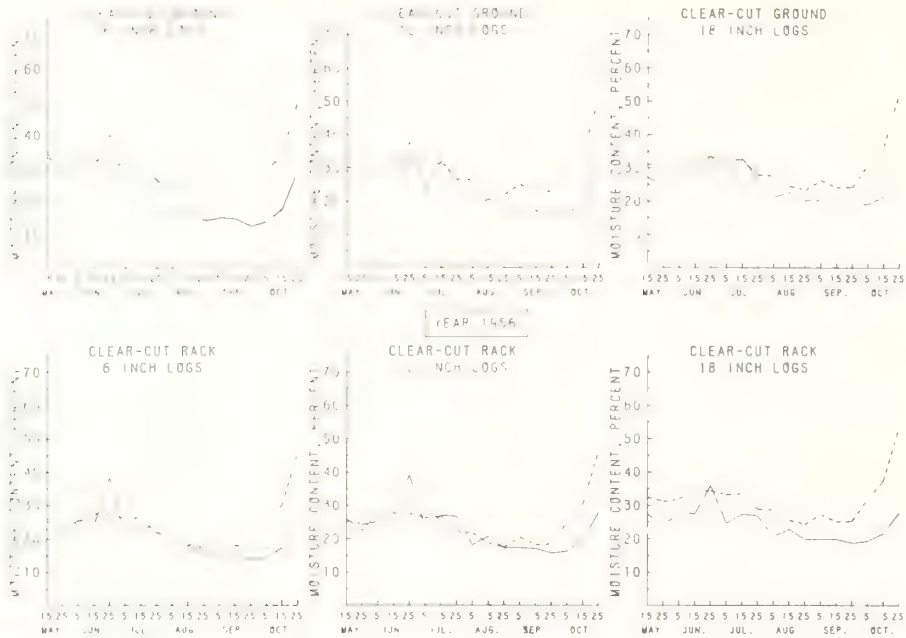
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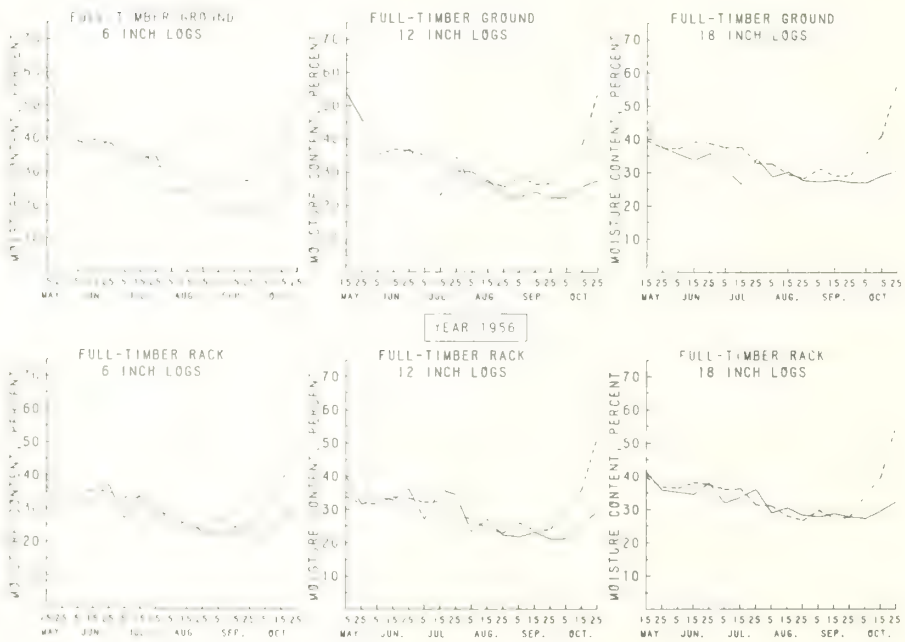
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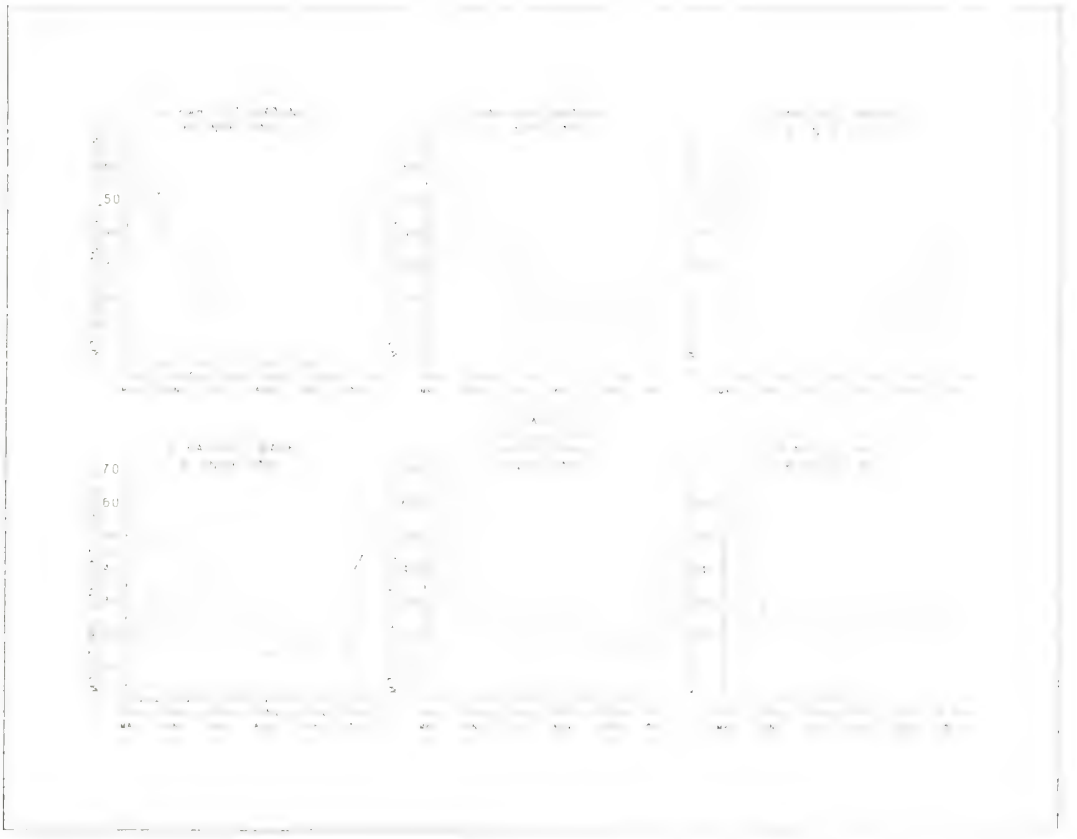
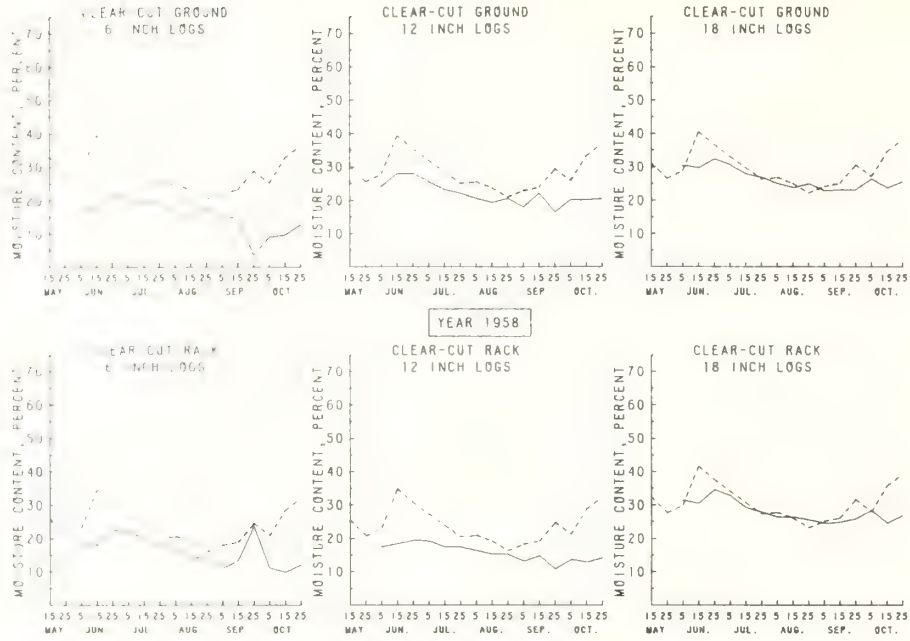
MAY JUN JUL AUG SEP OCT

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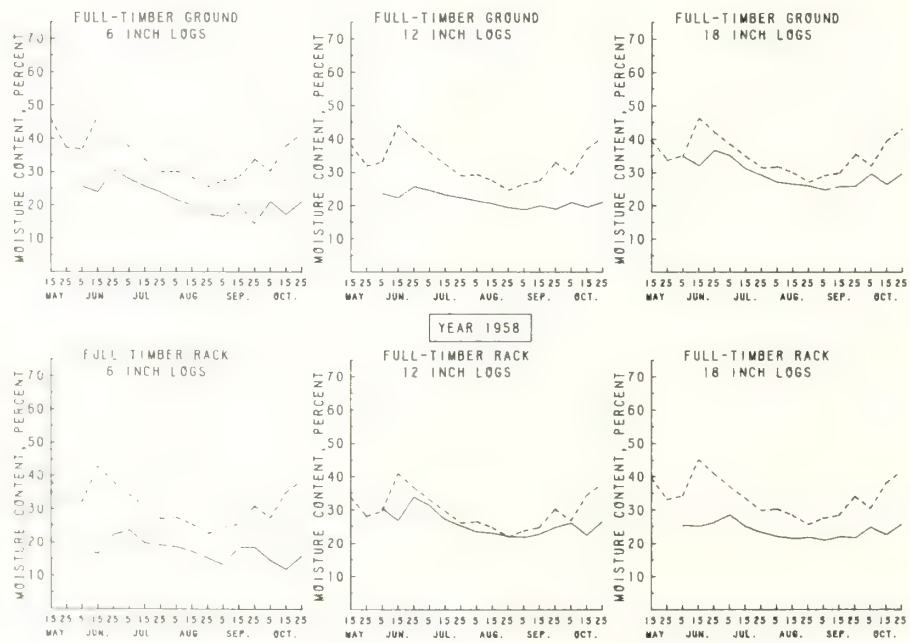
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.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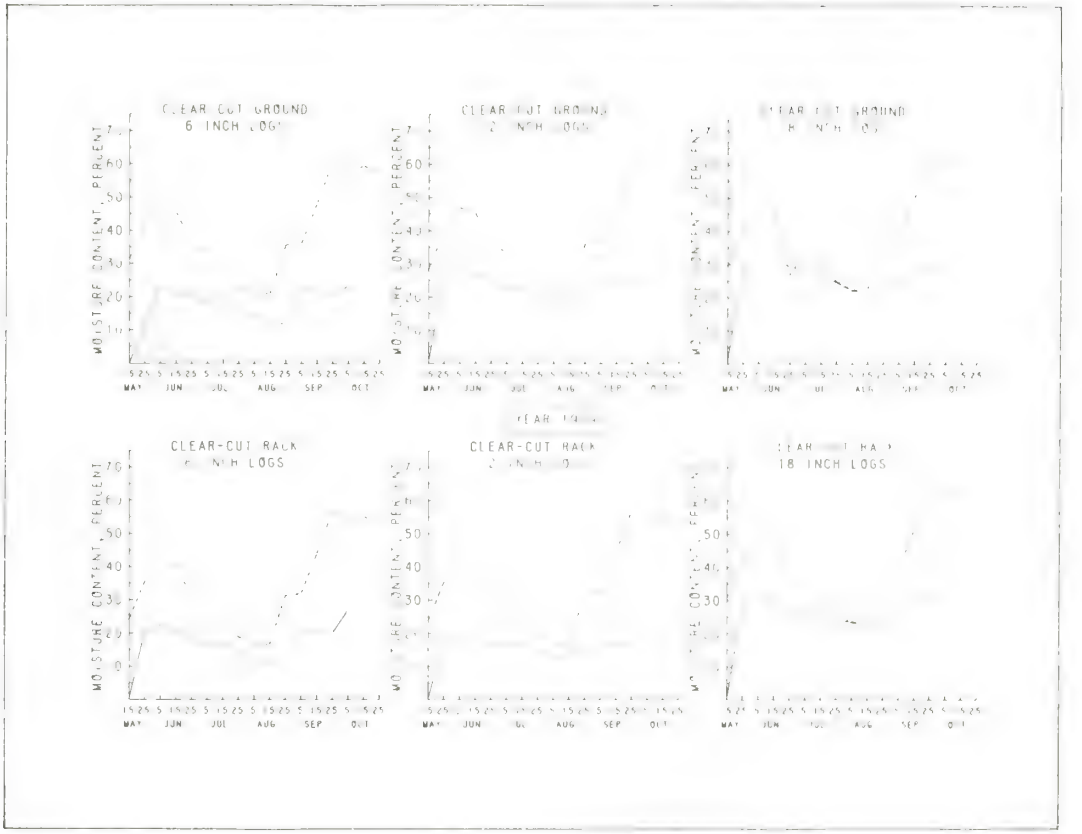
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.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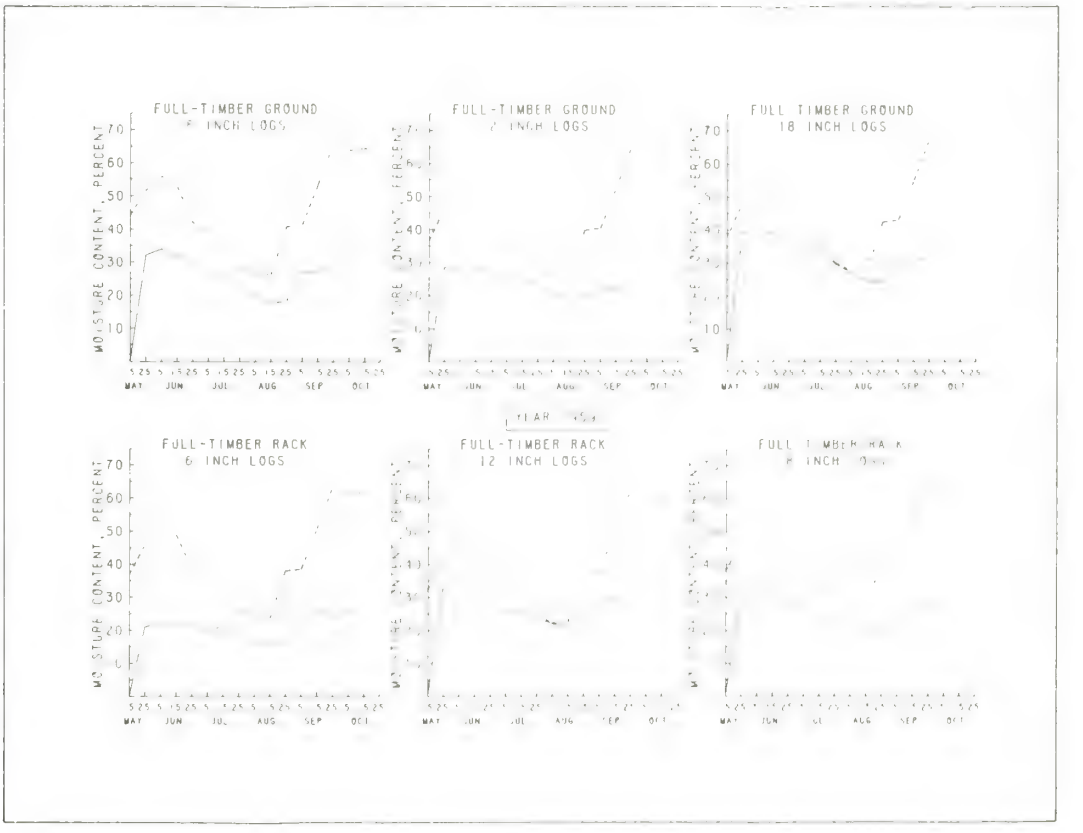
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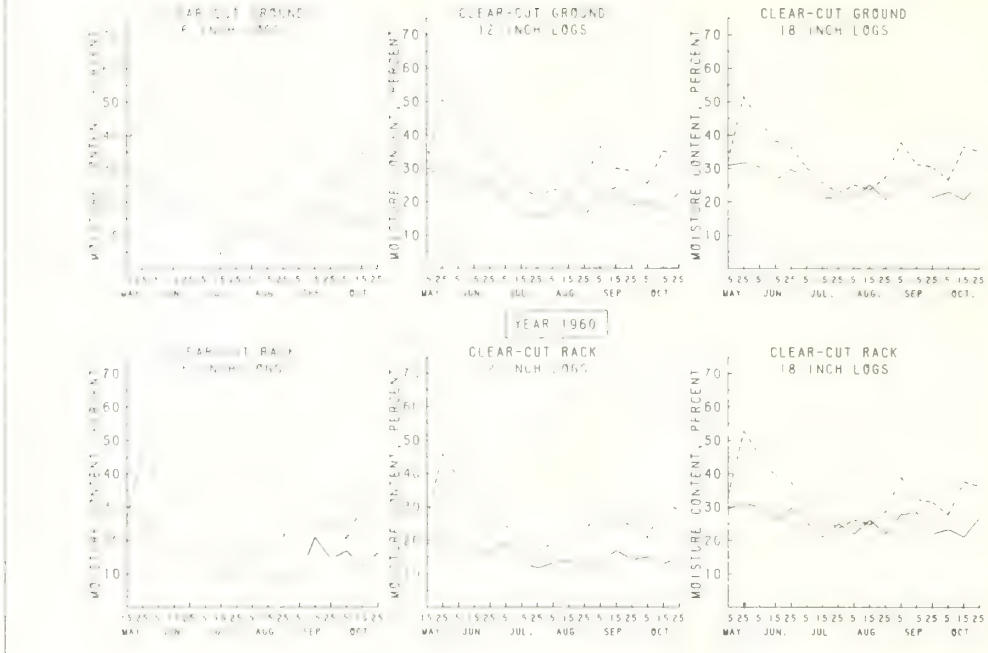
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JUL
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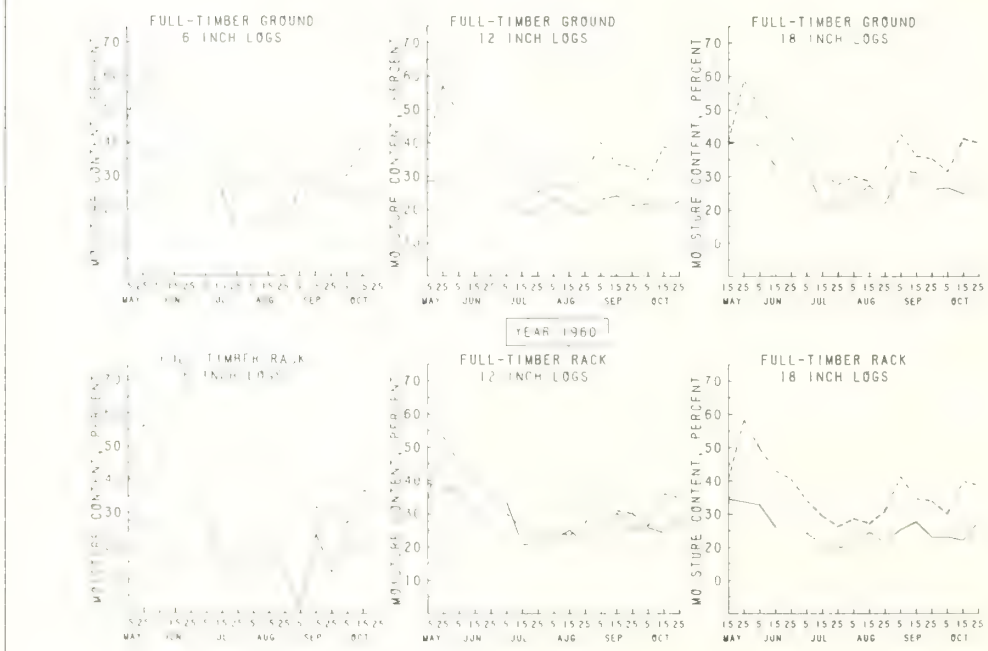
SEP
OCT
YEAR 1960
CLEAR-CUT RACK
18 INCH LOGS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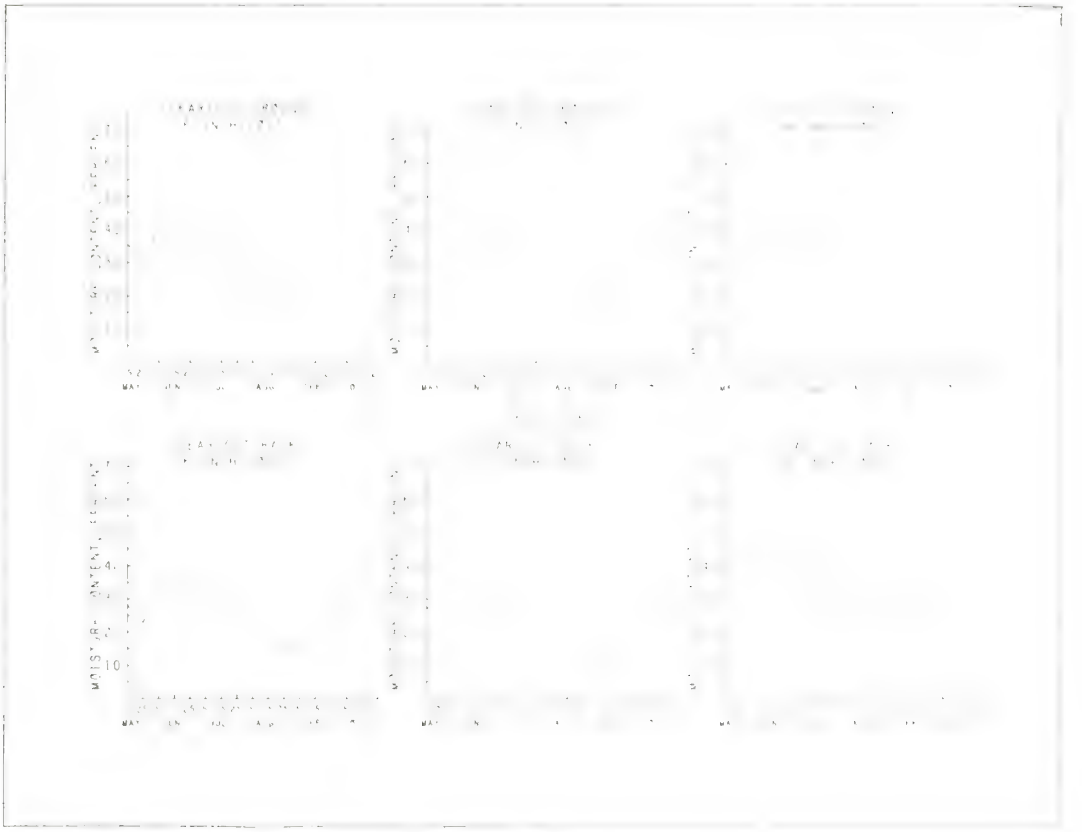
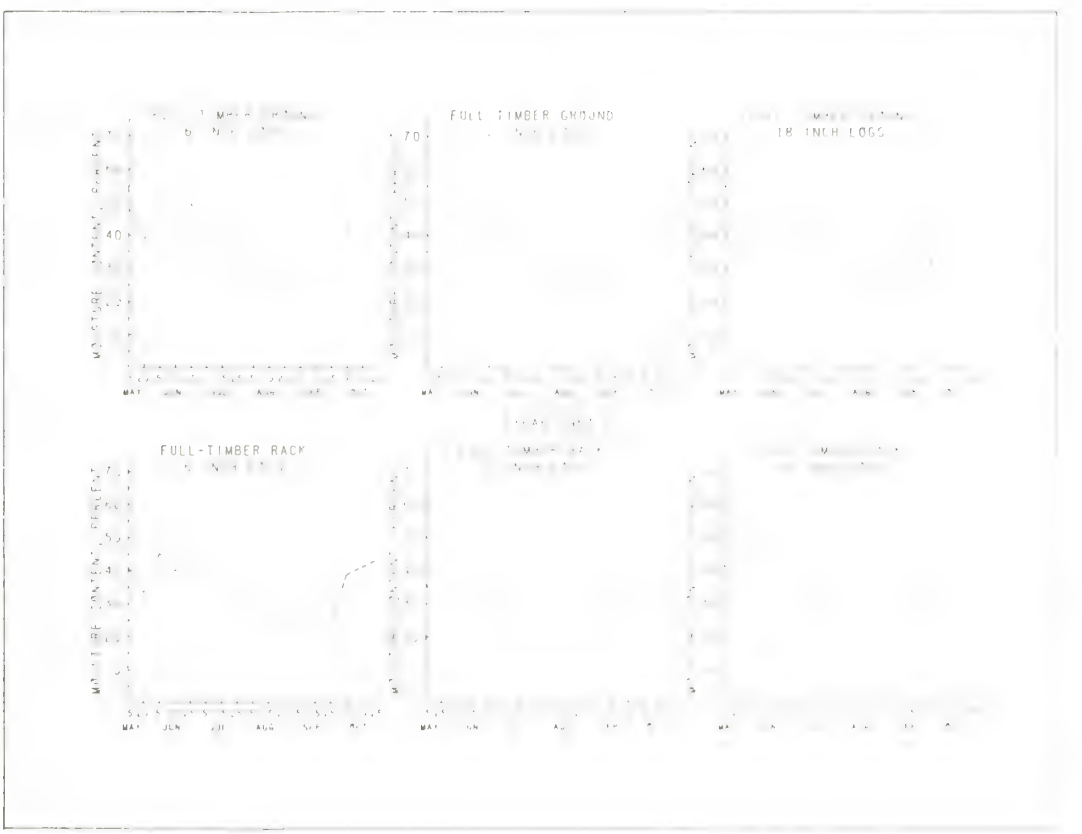
JUN
JUL
AUG
SEP
OCT
YEAR 1960
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS

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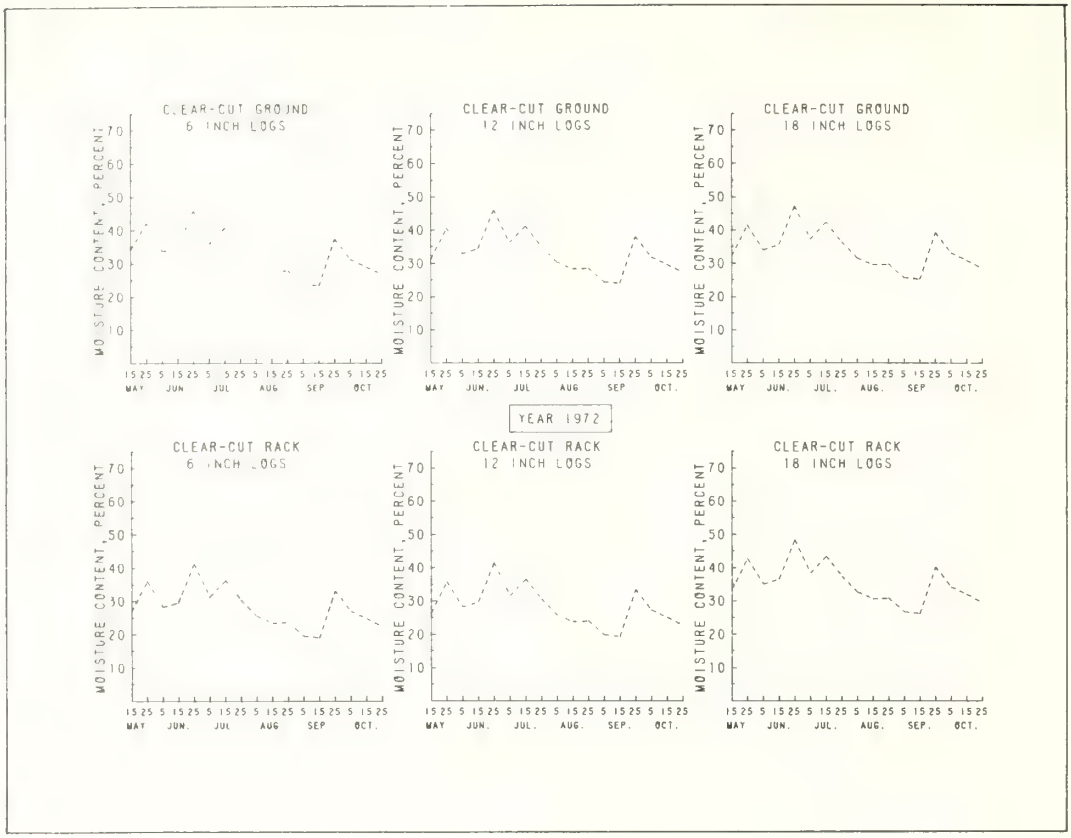
18 INCH LOGS
FULL-TIMBER RACK


CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
MOISTURE CONTENT, PERCENT
YEAR 1972
CLEAR-CUT RACK
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CLEAR-CUT RACK
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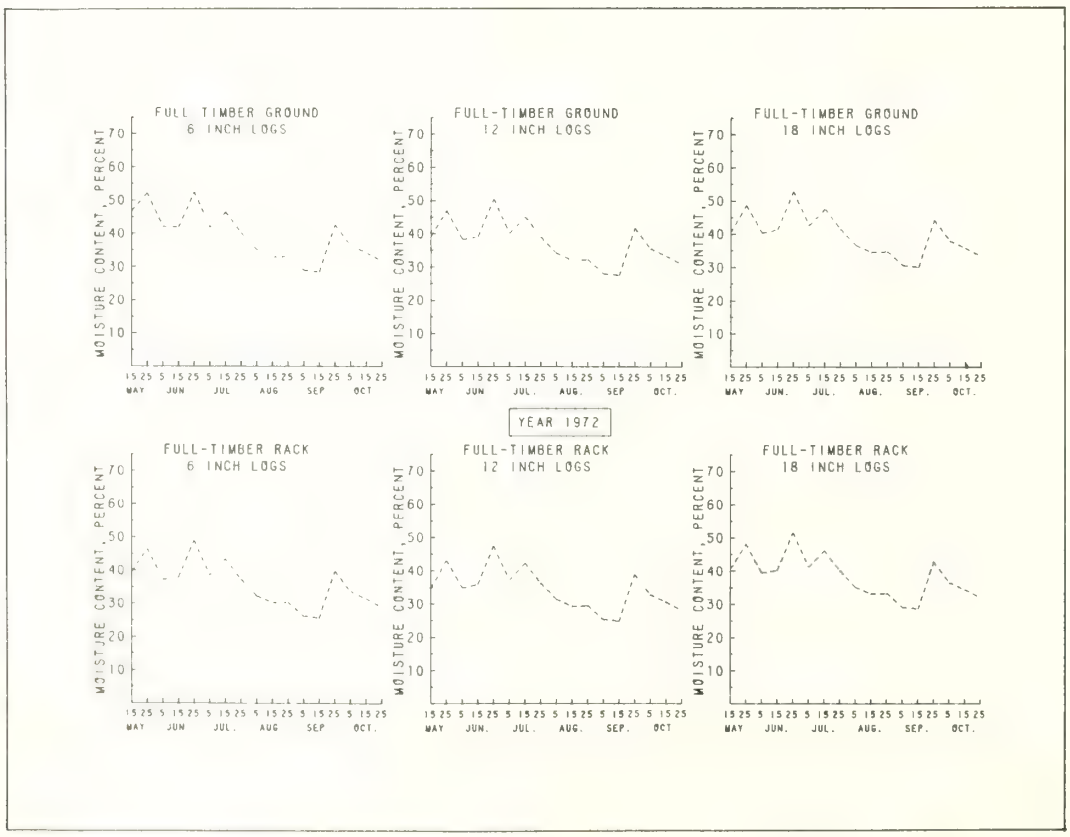
CLEAR-CUT RACK
18 INCH LOGS
MAY JUN JUL AUG SEP OCT

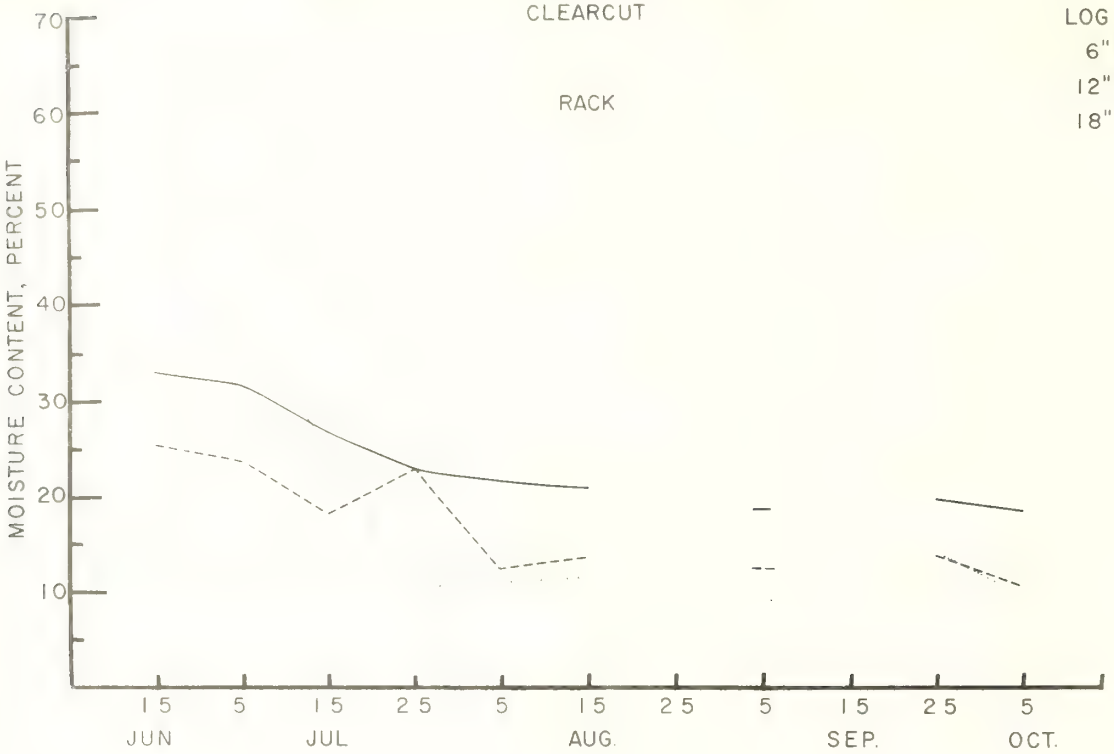

FULL TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
MOISTURE CONTENT, PERCENT
YEAR 1972
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MAY JUN JUL AUG SEP OCT

APPENDIX B

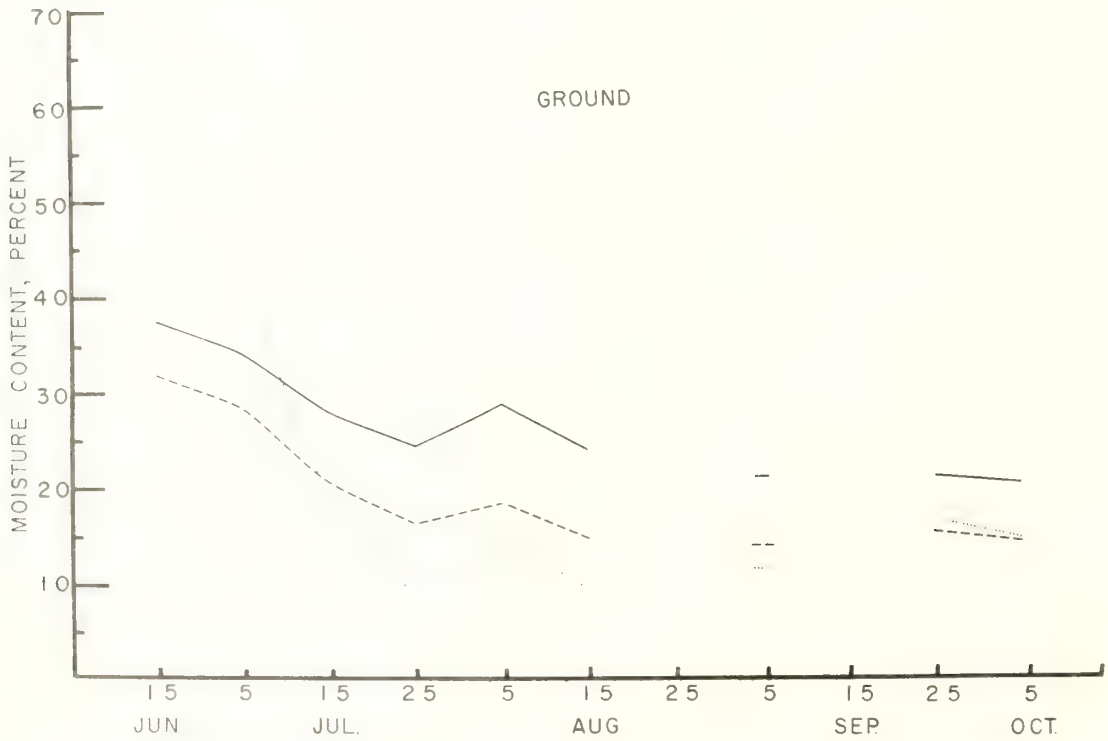
Large fuel moisture content curves for the portion of the study conducted at Boise Basin Experimental Forest.

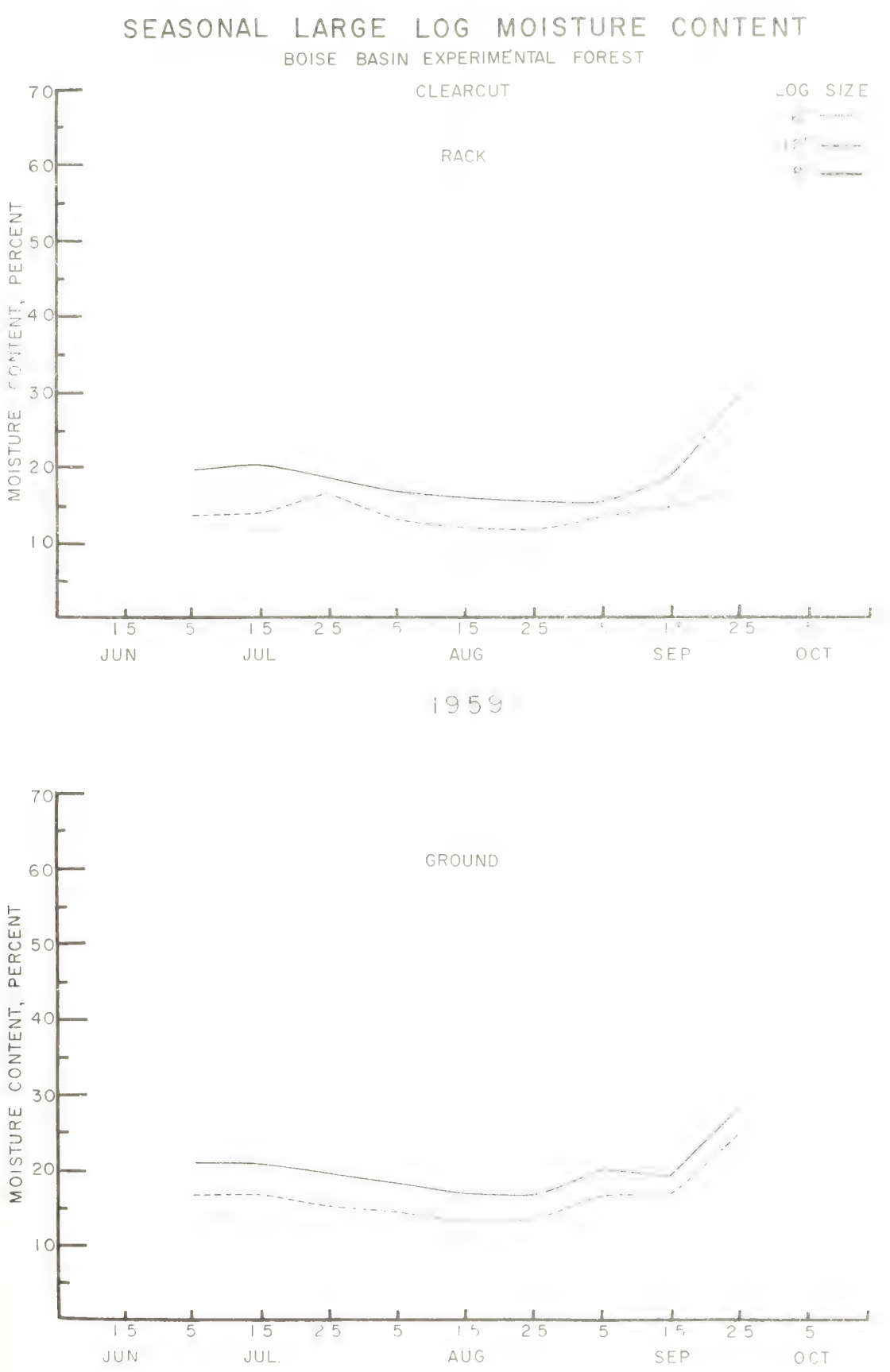
SEASONAL LARGE LOG MOISTURE CONTENT

BOISE BASIN EXPERIMENTAL FOREST
CLEARCUT



1958




SEASONAL LARGE LOG MOISTURE CONTENT
BOISE BASIN EXPERIMENTAL FOREST
CLEARCUT
LOG SIZE
RACK
MOISTURE CONTENT, PERCENT
70
60
50
40
30
20
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15
5
15
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5
15
25
5
15
25
JUN
JUL
AUG
SEP
OCT
1959
GROUND
MOISTURE CONTENT, PERCENT
70
60
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20
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5
JUN
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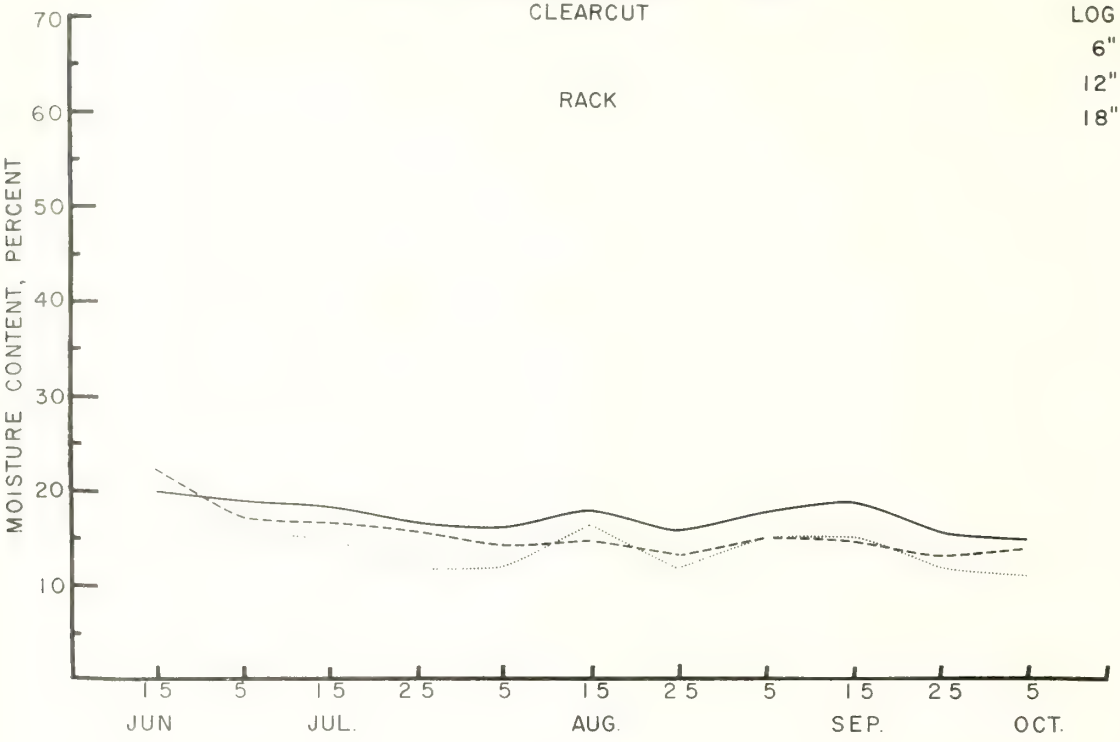
SEASONAL LARGE LOG MOISTURE CONTENT

BOISE BASIN EXPERIMENTAL FOREST
CLEARCUT



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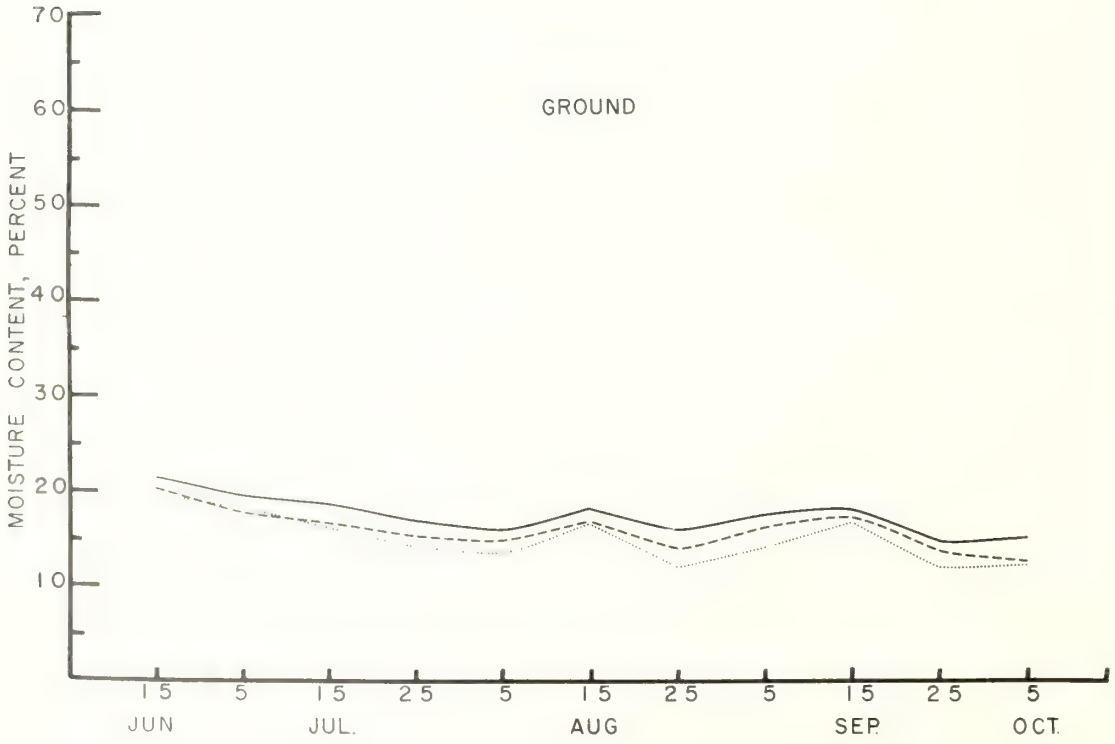

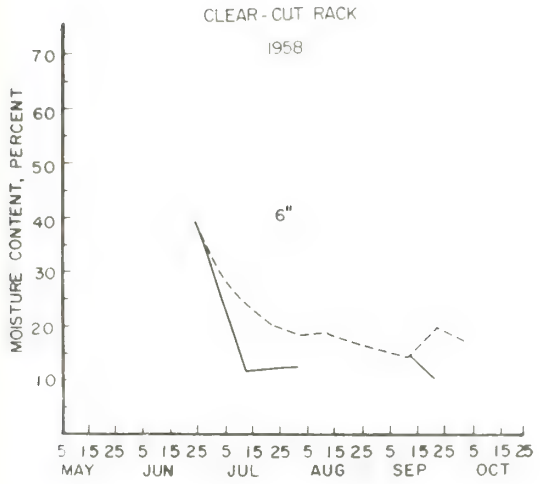
CLEAR - CUT RACK
1958
6"
MOISTURE CONTENT, PERCENT
70
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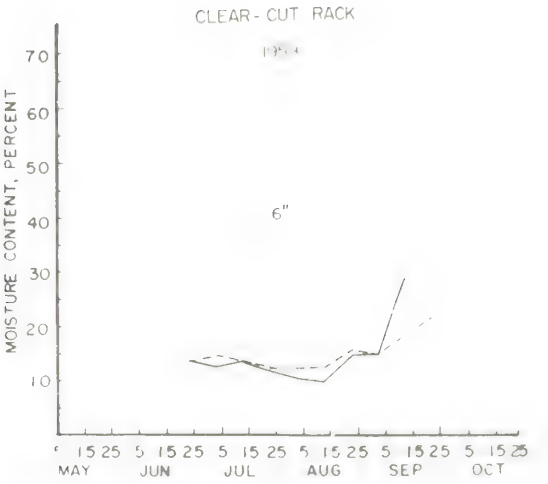
MAY JUN JUL AUG SEP OCT


CLEAR - CUT RACK
6"
MOISTURE CONTENT, PERCENT
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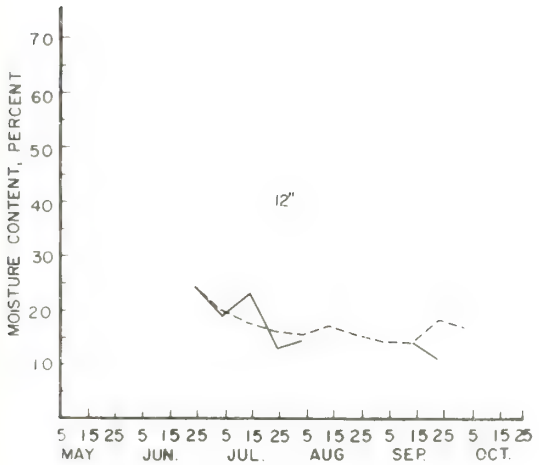
MAY JUN JUL AUG SEP OCT


12"
MOISTURE CONTENT, PERCENT
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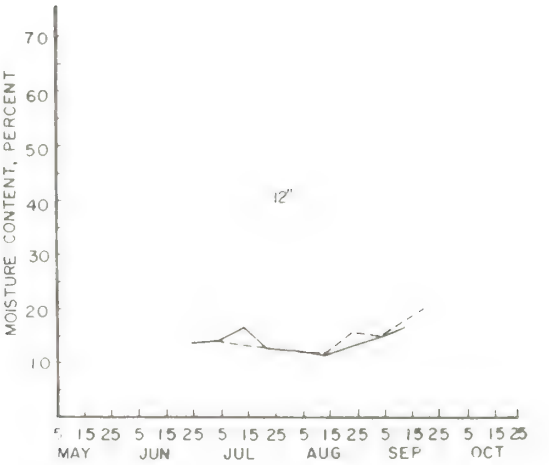
5 15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG SEP OCT.


12"
MOISTURE CONTENT, PERCENT
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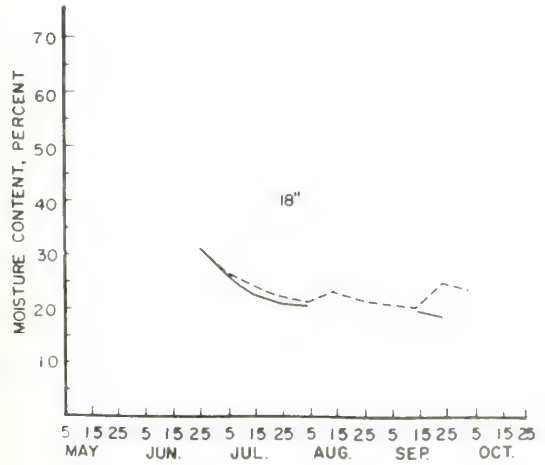
MAY JUN JUL AUG SEP OCT


18"
MOISTURE CONTENT, PERCENT
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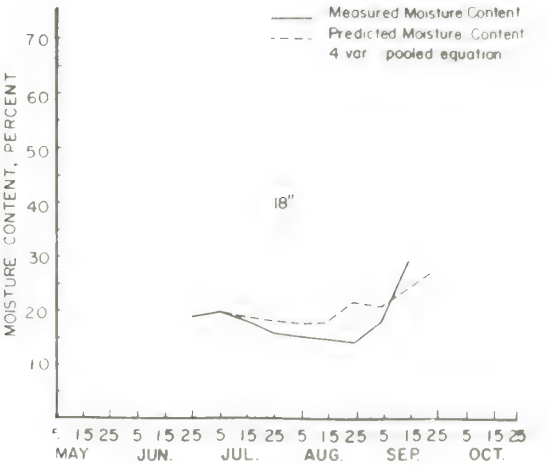
MAY JUN. JUL. AUG. SEP. OCT.


Measured Moisture Content
Predicted Moisture Content
4 var pooled equation
18"
MOISTURE CONTENT, PERCENT
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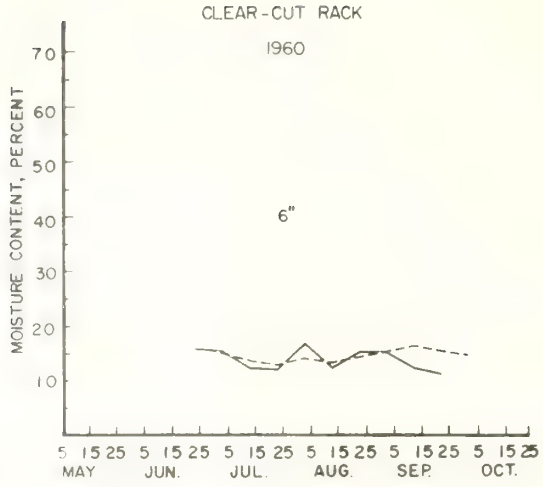
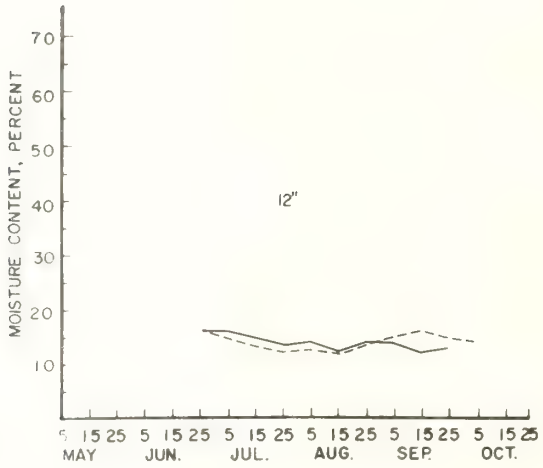
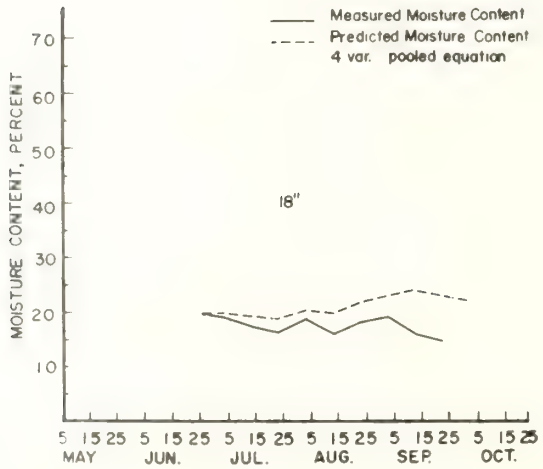
MAY JUN. JUL. AUG. SEP. OCT.







U.S. GOVERNMENT PRINTING OFFICE: 1975 O-573-228 : 2 REGION NO. 6

Brackebusch, Arthur P.

1975. Gain and loss of moisture in large forest fuels. USDA For. Serv. Res. Pap. INT-173, 50 p., 6 ref. (Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.)

Equations for predicting moisture in large fuels were developed from data gathered at Priest River Experimental Forest and Boise Basin Experimental Forest. The most important variables were beginning moisture content of the fuel, duration of precipitation, amount of precipitation, and the sum of the mean temperature of the observation period. Sensitivity and precision of the equations are weak. Predictions could be used as a guide. Moisture content of logs varied according to type of exposure.

OXFORD 431.2, 111.1, 181.7. KEYWORDS: fuel moisture content, fire weather, fire-danger rating.

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A SURVEY OF FACTORS AFFECTING REGENERATION OF ROCKY MOUNTAIN DOUGLAS-FIR

Russell A. Ryker

USDA Forest Service Research Paper INT-174, 1975
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Ogden, Utah 84401

USDA Forest Service
Research Paper INT-171
1976

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Russell A. Ryker

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

THE AUTHOR

RUSSELL A. RYKER is a Research Silviculturist for the Idaho Batholith Ecosystems research work unit of the Intermountain Station at Boise, Idaho. He received his B.S. (Forestry) degree in 1954 and M.S. (Forestry) degree in 1962 from the University of Missouri. From 1956 to 1963, he conducted research in the silviculture of central hardwoods for the Central States Station. He worked with the silviculture project at Moscow, Idaho, from 1963 until moving to Boise in 1967.

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SETTING	3
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ABSTRACT

To help delineate regeneration problems before developing a research program, I conducted a field reconnaissance in 1968 and 1969, of Rocky Mountain Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco) cutting areas in Forest Service Regions 1 and 4. From file records and field measurements, I obtained information about topography, soils, seedbed, shade, competing vegetation, opening size, habitat type, and history of treatment. Success of Douglas-fir regeneration is presented as percent milacre stocking. Results indicate that the effects of various regeneration methods and the success expected depend largely upon habitat type. Thus, attempts to generalize about seedbed, shade, and other species requirements can be misleading. Results were used to develop a research program for regeneration of Douglas-fir. Problem solutions seemed to center around the need for more careful administration of planting operations and plantation protection and for development of silviculture prescriptions to match species requirements and site potential.

INTRODUCTION

Rocky Mountain Douglas fir (*Pseudotsuga menziesii* var. *glauca*) occurs in mountainous areas throughout the Rocky Mountain States (fig. 1), and the Douglas-fir forest type occupies about 22 percent of the total acreage of commercial forest land. Douglas-fir itself accounts for about 20 percent of the cubic-foot volume and about 23 percent of the board-foot volume on these acres (Wilson and Spencer 1967). In Idaho alone, Douglas-fir is the principal commercial forest type on 4.8 million acres. This is nearly one-third of Idaho's commercial forest land, and 75 percent of these acres are in southern Idaho (Wilson 1962). Montana also has many acres of the Douglas-fir type. Douglas-fir is the major forest type on 11.7 million acres of commercial forest land in Nevada, Utah, Idaho, Montana, and eastern Washington.

Besides the timber values, Douglas-fir forests have major recreation and esthetic values. They are also important watershed cover and grazing lands.

Despite the obvious importance of the species, little research has been conducted to date on stand establishment of Rocky Mountain Douglas-fir in the Intermountain area. There are several reasons for this lack of research. In earlier years, most cutting was done in moist habitats and regeneration was usually adequate. Also, in those days, much cutting left a residual stand; so attention was not focused on any reproduction deficiencies that might have occurred (C. A. Wellner, unpublished report, Forestry Sciences Laboratory, Moscow, Idaho).

In recent years, clearcutting has been the dominant method of harvest. In clearcuts in southern Idaho (south of the Salmon River), central Montana, and on severe sites in western Montana, northern Idaho, and northeastern Washington, Douglas-fir reproduction is usually sparse or absent. Research on Douglas-fir stand establishment has become an urgent need.

In mid-1967, I began studying Douglas-fir stand establishment. Because of the diversity of conditions within the species range and the dearth of previous research on this variety of the species, I made a field reconnaissance to locate problems and to determine the kinds of research needed to solve them. This survey was conducted during the 1968 and 1969 field seasons.

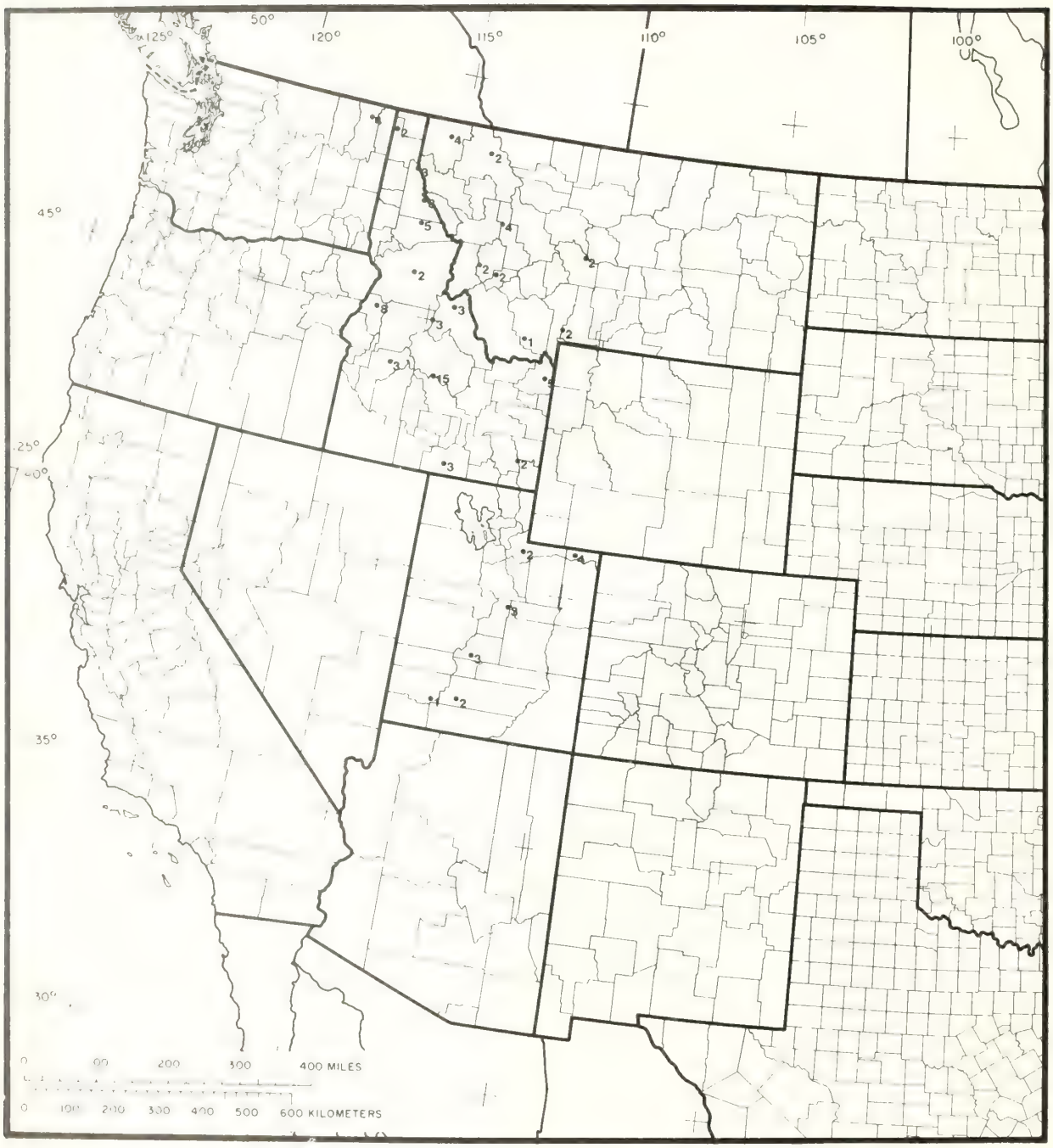


Figure 1.--The range of Rocky Mountain Douglas-fir (from Little 1971). Numerals indicate the number of areas sampled in the general locale of each black dot.

SETTING

Site Conditions

The different and distinct climates that occur within the Intermountain area are due to several factors.

The area extends for 900 miles of latitude and markedly different temperatures are exhibited within this great range.

The north-south orientation of mountain ranges exerts important influences on climate. Areas on the windward side receive greater amounts of precipitation than areas on the leeward side. Mean annual temperature decreases about 3° F for each 1,000-foot rise in elevation. Other factors, such as wind, humidity, cloudiness, and radiation, are similarly modified by the topography.

In northern Idaho and northwestern Montana, a strong maritime influence penetrates to the Continental Divide. The long, wet winters and comparatively short summer drought period of this area are more favorable for tree establishment than are climatic conditions throughout the remainder of the study area.

The country east of the Continental Divide gets frequent cold and dry air masses from Canada during the winter and persistent warm southerly winds from Mexico and the Gulf of Mexico in the summer.

The pattern of climates throughout the Intermountain area (U.S. Department Commerce 1968) suggests that, in general, conditions are probably most favorable for tree establishment in northern Idaho and northwestern Montana, becoming progressively less favorable farther south and abruptly less favorable east of the Continental Divide.

The diversity of climates is accompanied by an equally impressive diversity of geology and soils. Major portions of the area are represented by uplifted sedimentary formations and by volcanic, granitic, and basaltic formations. Soils range from highly erodible to quite stable, from nutrient rich to somewhat nutrient deficient and from droughty to moist. When combined with environmental differences fostered by geographic position and varied topography, soil diversity creates a complex pattern of site conditions.

Figure 2.--In this western hemlock habitat in northern Idaho, Douglas-fir is a relatively short-lived seral tree. It establishes more readily in exposed situations (clearcuts) here than it does in other habitats, but later growth is hindered by competition from better adapted species.

Species Behavior

Within a range extending more than 2,000 miles from north to south, Rocky Mountain Douglas-fir grows in widely diverse environments (fig. 2-6). Environmental variety has led to physiological and ecological diversity within the species.

Frothingham (1909) suggested that, under moist conditions, Douglas-fir reproduces better in the open than under drier conditions where it requires some protection by other species, which it eventually replaces. Krajina (1965) recognized this for Douglas-fir in Canada. Krauch (1956), working in the southern Rockies, found that shade favored seedling establishment and early growth. In ecological terms, Douglas-fir is a seral species on moister sites and a climax species on somewhat drier sites.

The Daubenmires (1968) classified the forest vegetation of eastern Washington and northern Idaho into 22 habitat types, which they considered to be ". . .the basic ecologic subdivisions of landscapes." Each habitat type has a distinct potential as to sere and climax, and is recognized by a distinctive combination of overstory and understory at maturity. Three of these habitat types have Douglas-fir as the major climax species. In five other more moist habitat types, it is a seral species.

In central Idaho, preliminary forest habitat type work indicates that Douglas-fir grows in 29 habitat types. It is a climax species in 14, a major seral species in 10, and a seral species in certain parts of the range of the other 5 habitat types.

Before we can confidently predict how Douglas-fir will respond to different treatments, especially in the regeneration portion of the life cycle, we must first identify differences in site conditions and then determine how the species responds to each particular set of conditions. Results of my field reconnaissance emphasize this point.

Figure 3.--In this western redcedar--hemlock stand, [illegible] cover to [illegible] the growth of [illegible] trees.

Figure 4.--Douglas-fir regeneration under a larch--ponderosa pine--Douglas-fir [illegible] stand. [illegible] surrounding trees.

Figure 5.--These stands in south-central Idaho are composed almost entirely of Douglas-fir and lodgepole pine. Regeneration of Douglas-fir on these habitats is much more difficult than on those depicted in figures 2-4.

Figure 6.--In the high plateau country of southern Utah, Douglas-fir is often a major component of the overstory, but is only a minor component of the understory, which is dominated by subalpine fir and Engelmann spruce. When the photo was taken (1968) there were still no tree seedlings in this 3-year-old opening.

OBJECTIVES

To delineate Douglas-fir regeneration problems, a field survey was conducted to identify and superficially characterize the factors of environment most closely associated with the establishment of new stands of Rocky Mountain Douglas-fir. More specifically, the objectives were: (1) to describe the problem effectively and (2) to furnish leads and direction for planning a study program.

The data obtained in this survey depict only the relative degree of success of Douglas-fir under different site conditions. They should not be construed to be a precise measure of the success of the overall stand-regeneration program of any National Forest or of Region 1 or 4. For instance, I did not attempt to evaluate the success of other species, and many Douglas-fir plantations in northern Idaho and northwestern Montana had other species seeding in and regenerating the areas. Also, some areas were planted with a mixture of species, including Douglas-fir. These areas were not sampled because of the futility of determining the number and planting location of trees of each species--rarely are they planted in uniform patterns over an entire cutting area. To get a good estimate of overall success, I would have needed a representative sample of all Douglas-fir cutting areas. The sample was restricted so as to get as wide a range of site conditions as possible within alloted time and resources.

METHODS

My field survey was limited to areas that had been cut within the past 15 years. In all, I sampled 95 cutting areas in 26 National Forests, 12 in Region 4, and 14 in Region 1 (fig. 1 and appendix I). Though I attempted to sample areas in different silviculture systems, most were clearcuts.

On each cutting area, I sampled Douglas-fir reproduction along two transects on each major aspect. These transects ran from the downslope timber edge to the top edge of the openings. Along each transect, I attempted to locate 10 circular milacre plots at approximately equal intervals, beginning under the canopy at one edge and ending under the canopy at the other edge. Sometimes I took more than 10 plots. If my estimate of the distance across the opening was short, I continued to take plots at equal distances until I reached the stand edge. If the opening was small, I took fewer plots per transect because minimum spacing between plots was one-half chain.

Data are presented in terms of milacre stocking computed by dividing the number of plots with one or more trees by the total number of plots sampled.

From file records and field measurements, I obtained information about the topography, soils, seedbed, shade, competing vegetation, habitat type, distance from timber edge, and history of each area since cutting.

I used the Daubenmires' key (1968) to name habitat types throughout northern Idaho and eastern Washington. Where a habitat classification system was not yet developed, I used the tree species that appeared to be climax to identify the habitat of our cutting areas and made no attempt to subdivide further on the basis of understory vegetation. Accordingly, data from all areas are summarized primarily by climax tree species, which are used to approximate the Daubenmires' habitat type series.

RESULTS

Because the northern part of the study area has a larger proportion of its forested areas in moist environments than does the south, I expected success of stand regeneration to decrease from north to south. Survey data show this to be generally the case. The percent of stocked milacre plots in our sampled areas decreased from about 26 in the north to 10 in the south for plantations and from about 47 to 20 percent on areas where natural regeneration was the goal.

Of even more interest than the geographical relationship was the apparent correspondence between habitat type and regeneration success. As I was sampling an area on the Payette National Forest about midway through the survey, my transects crossed a narrow ecotone between a subalpine fir (*Abies lasiocarpa*) type and a grand fir (*Abies grandis*) type. A Douglas-fir plantation was established and growing on the subalpine fir site, but on the grand fir site Douglas-fir survival was near zero. This same phenomenon was observed in other areas.

It became obvious that summarizing data for other factors without regard to habitat type could be misleading. I lacked a habitat type classification system for most of the area and compromised by ignoring understory vegetation and using the climax tree species to classify the habitat of each plot.

When summarized in this manner, the data in table 1 suggest that (1) greater stocking of natural Douglas-fir seedlings occur on the western hemlock habitat than on other habitats, and (2) Douglas-fir plantation success on the western redcedar and western hemlock habitats approximately doubles that of warmer and drier habitats. We sampled few direct-seeded areas, but those sampled had results similar to those of naturally seeded plots.

Table 1.-

Climax tree species[a]	Geographic area[b]	Planting: Number of plots	Planting: Percent stocked	Natural seeding: Number of plots	Natural seeding: Percent stocked	[illegible]: Number of plots	[illegible]: Percent stocked
Douglas-fir	1	110	20	47	47		42
	2	0	--	80	24	0	
	3	435	19	84	[illegible]	[illegible]	17
	4	0	-	61	39		
	Mean		19		36		
Grand fir	1	68	18	0			
	3	86	9	32	8	31	
	Mean		13		8		
Western redcedar	1	123	31	0	--	0	
Western hemlock	1	97	37	35	[illegible]	[illegible]	
Mountain hemlock	1	63	17	0	--	0	--
Subalpine fir	1	35	26	22	14	[illegible]	
	2	78	14	0		0	--
	3	125	22	20	5	0	--
	4	205	10	63		0	-
	Mean		15		[illegible]		27

[a]At the time of the survey, habitat types had not been described for the [illegible] northern Idaho. The data are summarized by climax tree species:
Douglas-fir, *Pseudotsuga menziesii* var. [illegible]
Grand fir, *Abies grandis* (Dougl.) Lindl.
Western redcedar, [illegible]
Western hemlock, [illegible]
Mountain hemlock, [illegible]
Subalpine fir, *Abies lasiocarpa* (Hook.) Nutt.

[b]The study area was divided into four geographic areas:

Geographic area	
1--Northern Idaho and western Montana	Clearwater, Coeur d'Alene, [illegible], Kootenai, Lolo, Sanpoil, and St. Joe.
2--Central Montana and eastern Idaho	Caribou, Gallatin, and [illegible]
3--Southwestern Montana and central Idaho	Beaverhead, [illegible], Payette, Salmon, and Sawtooth
4--Utah	Ashley, Cache, Dixie, Fishlake, Manti-LaSal, [illegible]

Stocking sometimes varies for habitats with the same climax species when they are located in different geographic areas. For instance, on subalpine fir habitats in areas 1 and 3 (table 1), plantation stocking is nearly double that on subalpine fir habitats in areas 2 and 4. Stocking also varied for grand fir habitats in areas 1 and 3, with twice the stocking of planted trees as area 3. Much of this diversity might have been explained by different habitat types if a classification system had been available that used understory vegetation criteria to further subdivide the range in environmental conditions for all areas.

The only data I have for habitat types common to more than one geographic area are tabulated below, for planted trees only:

Habitat type	Area 1 (Percent stocking)	Area 3 (Percent stocking)
Pseudotsuga menziesii/Physocarpus malvaceus (Douglas-fir/ninebark)	0	20
Pseudotsuga menziesii/Calamagrostis rubescens (Douglas-fir/pinegrass)	20	23
Abies lasiocarpa/Menziesia ferruginea (Subalpine fir/menziesia)	40	44

From this meager data, it appears that Douglas-fir plantation success may be comparable for the same habitat type in different geographic areas.

Seedbed.--On all habitats for which I have enough data for comparison, plantation stocking was higher on plots bared to mineral soil than on plots with litter on the soil surface (fig. 7). It is not clear why I found fewer planted trees where litter was present. Perhaps trees generally were not planted except where mineral soil was exposed by thorough site preparation, or perhaps debris was carelessly put into planting holes and contributed to high mortality. Also, competition might have been less rigorous on plots with bare mineral soil.

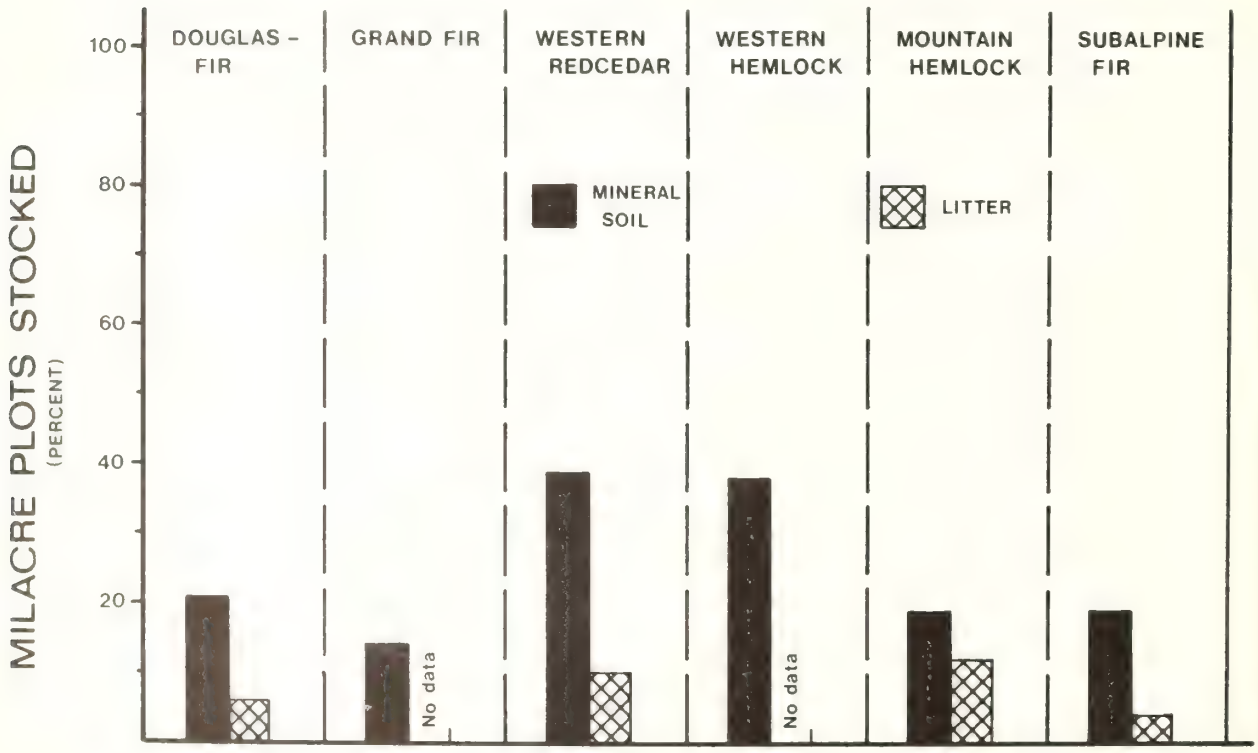
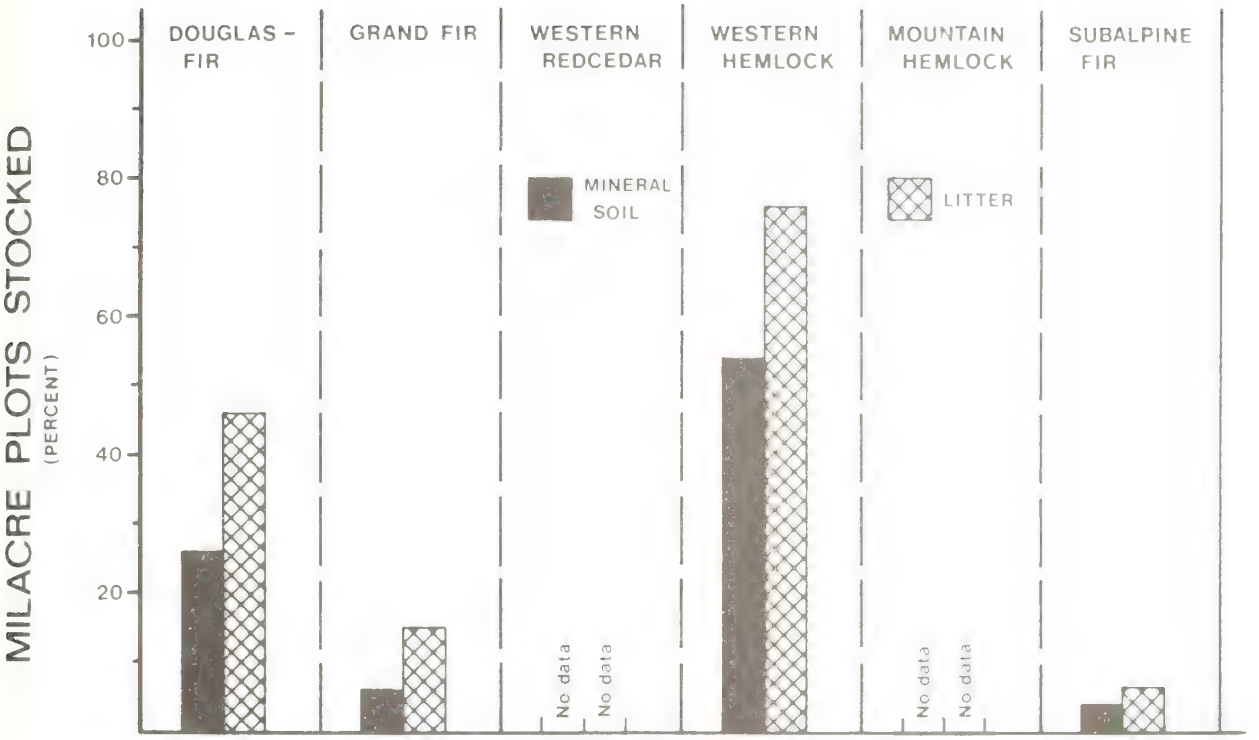


Figure 7.--Stocking of planted Douglas-fir expressed as percent of 1-milacre plots sampled. Success was better on bared soil surfaces on all habitats for which data were available.



Litter does not prohibit establishment of natural seedlings of Rocky Mountain Douglas-fir. In fact, I found a greater percent of litter-covered plots stocked than plots with exposed mineral soil (fig. 8). Hatch and Lotan (1969) reported similar findings in central Montana. Schmidt (1969) working in northwestern Montana found Douglas-fir less sensitive to seedbed conditions than western larch insofar as both seedling establishment and growth were concerned. Contrary to this, Shearer and Schmidt (1970) found more ponderosa pine and Douglas-fir seedlings on scarified plots than on undisturbed plots in western Montana. In my survey and in the study by Hatch and Lotan, some bare areas were created by logging disturbance. Others may have been caused by such disturbances as animal trampling, which may have caused seedling mortality. However, studies reported by Schmidt and by Shearer and Schmidt had definite site preparation treatments; other disturbances were held to a minimum.

When other environmental factors are equal, Douglas-fir will probably perform better in mineral soil than in litter. However, the preparation of a mineral soil seedbed does not seem to be as critical for Douglas-fir on some habitats as for other species, such as western larch. Further research is needed before seedbed requirements are known for the various habitats in which Douglas-fir grows.

Depth of organic matter.--The depth of organic matter on any relatively undisturbed forest site probably depends to a large extent on the habitat type of the site. Though I recorded the habitat of each plot, there were not enough data in each depth category to obtain dependable averages until I combined habitats. Therefore, organic matter data are confounded with habitat effects and are even more difficult to interpret than seedbed data.

I found natural seedlings of Douglas-fir established on plots with organic matter ranging in depth from 0 to 2 inches, but the greatest stocking was on plots with about 1-3/4 inches of organic matter. Stocking (1-milacre) of natural Douglas-fir seedlings by depth of organic matter was as follows:

Depth (Inches)	Depth (Centimeters)	Stocking (Percent)
0	0	30
1/2	1.3	33
3/4	1.9	41
1	2.5	50
1-1/4	3.2	48
1-1/2	3.8	68
1-3/4	4.4	72
2	5.1	64

However, about all that can be said at this point is (1) that Douglas-fir can become established through organic material on the surface, and (2) we need to study the microsuccession of the forest floor of various habitat types before offering an explanation of how organic matter affects young Douglas-fir seedlings.

Vegetational competition.--Because there were so many gaps in the data for natural seeding, my comparisons between levels of competition are based on planted-tree data only. On habitats where the greatest stocking is typically found, heavy competition appears to have reduced stocking (fig. 9), but on more severe sites I found about the

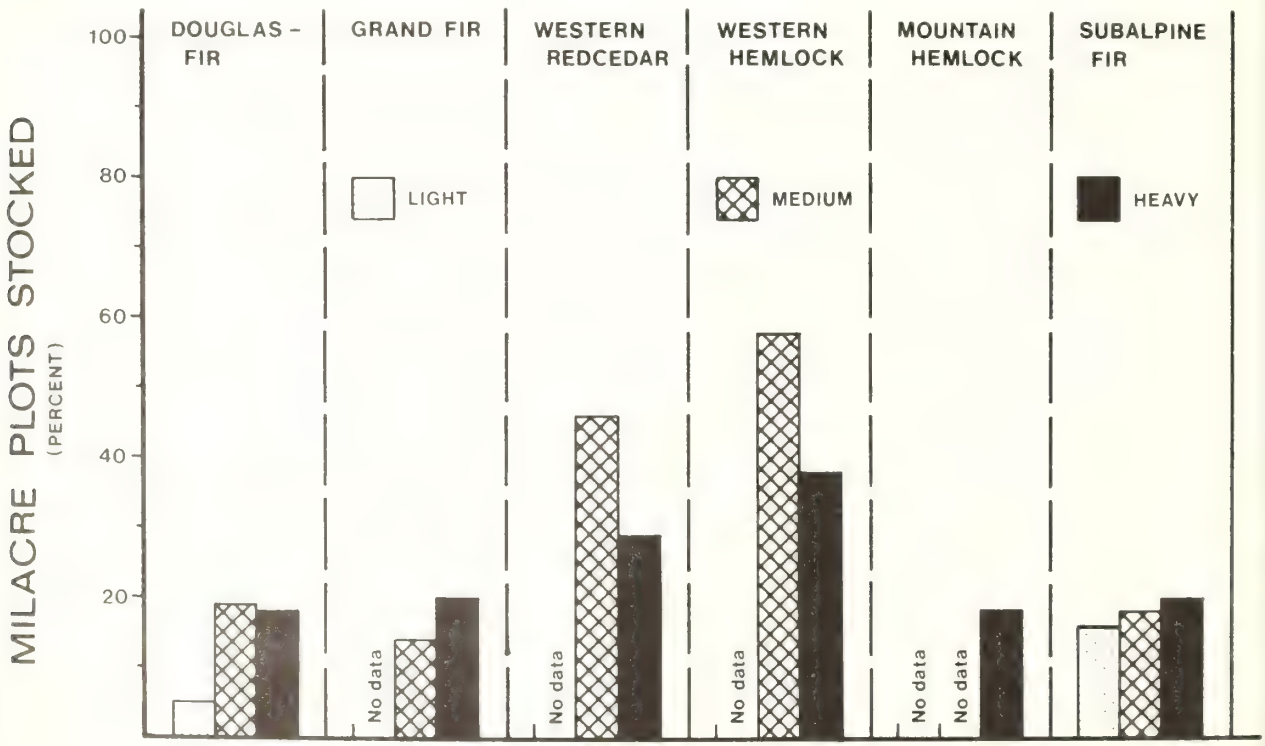


Figure 9.--On the western redcedar and western hemlock habitats, heavy competition appears to have reduced stocking. On more severe sites, as many or more trees were found where competition was greatest.

same number of trees, regardless of competition. We apparently need to strike a balance between vegetation left for protection against sun and wind, and vegetation removed to increase available water, light, and nutrients. This balance point is expected to differ with habitat and amount of logging debris left on the site.

Shade.--An important factor affecting survival of young Douglas-fir trees is the portion of daylight hours during which a tree is shaded. Only on western hemlock habitats were more trees found out in the open than where they received shade during part of the day (fig. 10). On all other habitats, more Douglas-fir trees were found under partial shade.

Shade was often from the surrounding stand, but not always. Sometimes logging debris, shrubs, and forbs offered protection, especially in clearcuts where debris had not been piled and burned.

The major benefit from shade is believed to be the amelioration of temperature and moisture extremes. The intensity of the light itself does not appear to limit the growth of trees in this area.

Distance from stand edge.--Most natural seedlings of Douglas-fir were found within 1 chain of the stand edge on Douglas-fir habitats. Milacre stocking decreased from 57 percent close to the stand edge to 9 percent at 4 chains or more into the opening. However, proximity to stand edge was not necessary for seedling establishment on moister habitats. For instance, milacre stocking on the western hemlock habitat averaged 65 percent close to the stand edge, but increased to 77 percent at distances of 1 to 3 chains from the edge. Larger openings relying on natural regeneration were not found in this habitat.

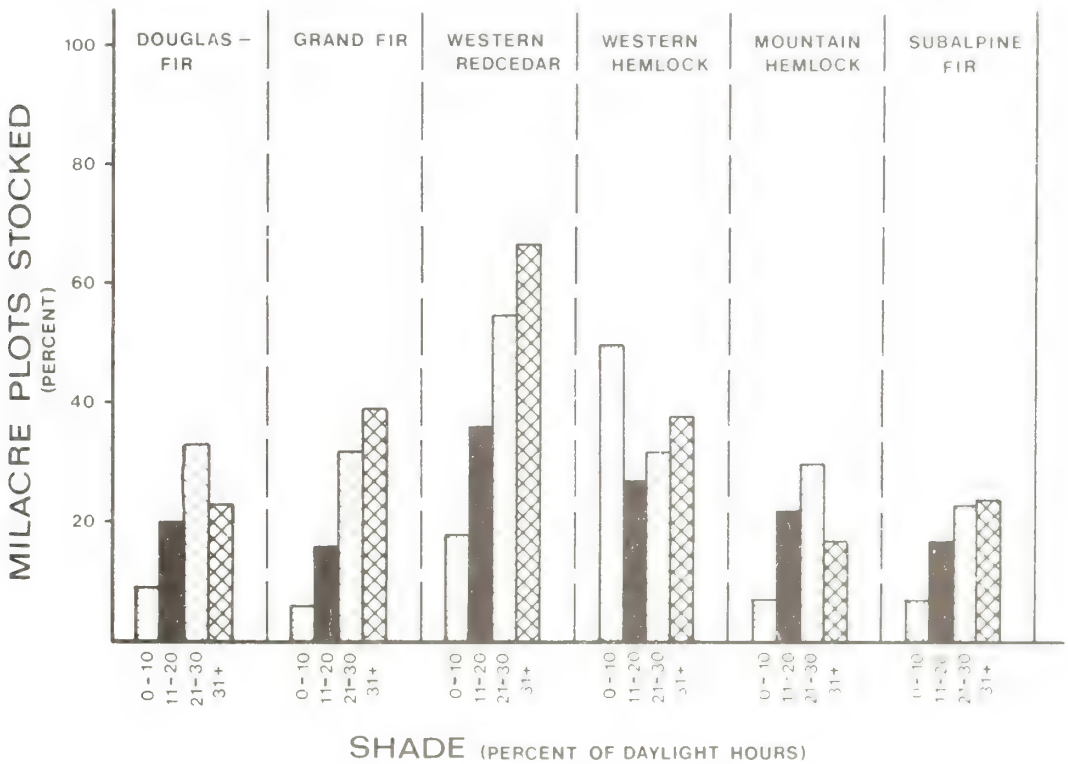


Figure 10.--More planted Douglas-fir trees survived on the western hemlock habitat when they received direct sunlight throughout the day. On the other habitats, shade during some portion of the day seemed to increase survival.

Seed dispersal patterns and differences in environment contribute to differences in effect of distance from stand edge on seedling establishment. Boe (1953) found the quantity of sound Douglas-fir seed that fell to the ground decreased rapidly from timber edge to about 4 chains. R. C. Shearer (personal communication, research silviculturist, Missoula, Mont.) has found the number of sound seeds required per established tree to differ greatly with changes in habitat. Therefore, on the drier sites the amount of seed reaching the middle of larger openings may not be sufficient for successful regeneration.

DISCUSSION

The intention of this survey was to determine where Douglas-fir regeneration problems exist. Admittedly, the results from a quick survey of this type are not conclusive and have a lot of holes. For instance, certain conditions were encountered so seldom in my sample that data are scarce or completely lacking for some categories in the summarization tables. Also, our comparisons of planting success on the basis of percent milacre stocking assumes that approximately the same number of trees were planted per acre on all habitats. It also assumes that handling and planting techniques and quality of nursery stock were generally comparable throughout the study area. It is probable that these assumptions have not been met in all cases.

Nevertheless, I am confident the data are sufficient for the stated purpose. They show us that the success of Douglas-fir regeneration varies with habitat, and that success has been low on sites where Douglas-fir attains climax status. In view of the great diversity of plantation success and of Douglas-fir sites in the Northern Rockies, this seems to be a logical conclusion. It also agrees generally with the results of previous work.

While studying factors affecting regeneration of western Montana clearcuts, Steele and Pierce (1968) observed that where wildfires have burned over large areas, south aspects are extremely slow to regenerate. They concluded that the south and west exposures need special consideration in determining the cutting method to be employed as well as in the treatment of the resulting slash. Larsen (1924) also points out the difficulty of obtaining regeneration on south aspects due to extremes in temperature and drought. These south-aspect sites are often Douglas-fir habitat types.

Boyd (1969) described natural regeneration trends in some northern Idaho western white pine stands. On moist habitats, even-aged silviculture systems resulted in adequate regeneration within 5 to 10 years. Drier habitats had a prolonged regeneration period, possibly exceeding 20 years, regardless of the silviculture system used. His dry sites were grand fir habitats, which are more moist than the Douglas-fir habitats.

Results from a recent planting study (manuscript in preparation) also confirm the effect of habitat on plantation success. In a planting test of species adaptation to high-elevation clearcuts, first-year survival was high (90 to 100 percent) on most plots regardless of habitat. By the end of the third year, however, survival was related to habitat types.

Failure to develop silviculture prescriptions compatible with ecological considerations was not the sole reason for generally low success of Douglas-fir plantations over the 15 years prior to 1968. Browsing and trampling by domestic livestock caused immense damage in many plantations. Low vigor of planting stock from the nursery was often suspected. This may have been caused by cultural practices in the nursery, or by lifting, handling, and storage procedures that did not adequately maintain tree vigor until planting time. The planting procedure was also suspect. A poor selection of planting spot, improper placement of roots, improper planting depth, and air pockets and debris in the planting hole undoubtedly have reduced survival and growth of planted trees. In the Intermountain region, Douglas-fir seems to be more sensitive than other species to mishandling. Therefore, it is imperative that all procedures be carefully performed.

For natural seeding, one or more of a number of factors may have contributed to a lack of regeneraton on any specific area. The budworm (*Choristoneura occidentalis* Freeman) was widespread in Montana and Idaho during the 15-year regeneration period studied. Dewey (1970) found it to be a serious pest to Douglas-fir cones. Squirrels and ground-dwelling rodents can seriously reduce the number of seeds available at germination time (Shearer and Schmidt 1970). Dwarf mistletoe, bark beetles, and root rot are other agents that reduce the vigor of Douglas-fir trees. The extent of damage from these agents is probably related in some degree to habitat type.

RECOMMENDATIONS

An accurate description of site potential is needed where research is done. A similar site evaluation must be made by the land manager using research results to prescribe silviculture treatments for a specific unit of land. Both evaluations appear to be indispensable to consistent success in Rocky Mountain Douglas-fir regeneration efforts.

Douglas-fir is important over a wide range of habitat conditions. Consequently, successful regeneration of individual stands will require knowledgeable use of different cutting systems, selection of applicable site preparation and artificial regeneration measures, and careful execution of each step of the selected treatments. What can be done with success on some sites may not succeed on others (appendix II).

The most logical approach for our research program would be to (1) develop a habitat type classification for the remaining forest lands in the five-State area sampled, (2) determine the requirements of the species, and (3) evaluate effects of different silvicultural systems and develop guidelines for regenerating stands on major habitat types that support Douglas-fir.

In the meantime, the land manager should give careful attention to all phases of each operation. For instance, in plantation establishment, he should make sure that seed is from good trees adapted to the planting site; that nursery practices produce vigorous planting stock; that stock vigor is maintained by careful lifting, handling, and storage; and that planting is carefully done. Though handling and planting requirements to maintain tree vigor are adequately known, further refinements, such as requirements for each species, will pay dividends. But, too often the big stumbling block is getting the job on the ground done in strict accordance with the prescription.

Recent cooperative efforts between the Lucky Peak Nursery, National Forest Administration, and Intermountain Forest and Range Experiment Station have resulted in substantial improvement in the vigor and quality of planting stock produced, and in th care and methods used for shipping, storing, and planting trees in Region 4. These efforts have raised the level of first-year survival for all species planted in the last 2 years. For Douglas-fir, this careful attention to every detail is absolutely necessary for reasonable success even on the better Douglas-fir sites.

Habitat type classification efforts are also underway in central Idaho and Montan. Preliminary classifications have been developed and tested, and publications presentin classification systems for Montana and central Idaho are being prepared. Parts of southern Idaho and Utah still need considerable fieldwork before a system can be developed for those areas.

We must now determine the requirements of Douglas-fir from different geographic areas and different habitats. This work has been initiated by Rehfeldt (1974a, 1974b) in northern Idaho and western Montana, but needs to be expanded to cover the rest of the Intermountain area.

We must also begin to develop silviculture prescriptions for major habitat types. When accompanied by careful attention to operational details, silviculture prescriptions aimed at fitting the capabilities of the site to the requirements of the species should attain a high degree of consistency in regeneration of Douglas-fir.

PUBLICATIONS CITED

Boe, Kenneth E.
1953. Western larch and Douglas-fir seed dispersal into clearcuttings. USDA For. Serv., North. Rocky Mt. For. and Range Exp. Stn. Res. Note 129, 2 p.

Boyd, R. J.
1969. Some case histories of natural regeneration in the western white pine type. USDA For. Serv. Res. Pap. INT-63, 24 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Daubenmire, R., and Jean B. Daubenmire.
1968. Forest vegetation of eastern Washington and northern Idaho. Wash. Agric. Exp. Stn., Wash. State Univ. Tech. Bull. 60, 104 p.

Dewey, Jerald E.
1970. Damage to Douglas-fir cones by *Choristoneura occidentalis*. J. Econ. Entomol. 63:1804-1806.

Frothingham, E. H.
1909. Douglas-fir: a study of the Pacific Coast and Rocky Mountain forms. U.S. Dep. Agric., For. Serv. Circ. 150, 38 p.

Hatch, Charles R., and James E. Lotan.
1969. Natural regeneration of Douglas-fir in central Montana. USDA For. Serv. Res. Note INT-85, 4 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

ajina, Vladimir J.
1965. Bioecoclimatic zones and classification of [illegible] Western North America 1:1-17.
auch, Hermann.
1956. Management of Douglas-fir timberland in the Southwest. USDA For. Serv., Rocky Mt. For. and Range Exp. Stn., Stn. [illegible]
rsen, E. A.
1924. Some factors affecting reproduction [illegible] Agric. Res. 28:1149-1157.
ttle, Elbert L., Jr.
1971. Atlas of United States trees. Vol. I. Conifers and important hardwoods. U.S. Dep. Agric. Misc. Publ. 1146. Washington, D.C.
hfeldt, G. E.
1974a. Local differentiation of populations of rocky Mountain Douglas-fir. Can. J. For. Res. 4(3):399-406.
hfeldt, G. E.
1974b. Genetic variation of Douglas-fir in the northern Rocky Mountains. USDA For. Serv. Res. note INT-184, 6 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
hmidt, Wyman C.
1969. Seedbed treatments influence seedling development in western larch forests. USDA For. Serv. Res. Note INT-93, 7 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
earer, Raymond C., and Wyman C. Schmidt.
1970. Natural regeneration in ponderosa pine forests of western Montana. USDA For. Serv. Res. Pap. INT-86, 19 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
eele, Robert W., and William R. Pierce.
1968. Factors affecting regeneration of western Montana clearcuts. Univ. Mont. For. and Conserv. Exp. Stn. Bull. 33, 26 p.
S. Department of Commerce.
1968. Climatic atlas of the United States. Environ. Sci. Serv. Adm., Washington, D.C.
lson, Alvin K.
1962. Timber resources of Idaho. USDA For. Serv. Intermt. For. and Range Exp. Stn. For. Surv. Release 3, 42 p. Ogden, Utah.
lson, Alvin K., and John S. Spencer, Jr.
1967. Timber resources and industries in the Rocky Mountain States. USDA For. Serv. Resour. Bull. INT-7, 67 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

APPENDIX I

Number of areas sampled by National Forests and Regions 1 and 4 (R-1 and R-4)

Region	Forest	Areas sampled (number)
Northern (R-1)	Beaverhead	1
	Bitterroot	2
	Clearwater	5
	Coeur d'Alene	3
	Colville	4
	Deerlodge	2
	Flathead	2
	Gallatin	2
	Kaniksu	2
	Kootenai	4
	Lewis & Clark	2
	Lolo	4
	Nezperce	2
	St. Joe	3
Intermountain (R-4)	Ashley	4
	Boise	3
	Cache	2
	Caribou	5
	Challis	3
	Dixie	3
	Fishlake	3
	Manti-LaSal	3
	Payette	8
	Salmon	3
	Sawtooth	18
	Wasatch	2
		95

APPENDIX II

silviculture system, and habitat (climax tree)

Climax tree species	Silvicultural system	Regeneration method	Seedbed type				
			Mineral	Litter	Ash	Moss	Muck
Douglas-fir	Clearcut	Planting	22	8	[1] 14		
		Natural seeding	16	9	--	--	--
		Direct seeding	52	--	--	--	--
	Strip cut	Planting	18	0	8	--	--
		Natural seeding	60	86	--	--	--
		Direct seeding	--	--	--	--	--
	Group selection	Planting	21	[1] 17	--	--	--
		Natural seeding	56	58	--	--	--
		Direct seeding	[1] 0	0	--	--	--
Grand fir	Clearcut	Planting	14	[1] 0	--	--	--
		Direct seeding	6	--	--	--	--
	Seed tree	Natural seeding	6	15	[1] 0	--	--
Western redcedar	Clearcut	Planting	39	10	[1] 11	[1] 0	[1] 0
Western hemlock	Clearcut	Planting	42	--	--	--	--
	Group selection	Natural seeding	[1] 85	92	--	--	--
	Strip cut	Natural seeding	60	56	--	--	--
Mountain hemlock	Clearcut	Planting	19	12	--	--	--
Subalpine fir	Clearcut	Planting	20	5	20	6	--
		Natural seeding	5	10	--	--	--
		Direct seeding	29	[1] 14	--	--	--
	Group selection	Natural seeding	0	6	--	--	--
		Planting	0	0	--	--	--

[1] Based on fewer than 10 plots.

Ryker, Russell A.

1975. A survey of factors affecting regeneration of Rocky Mountain Douglas-fir. USDA For. Serv. Res. Pap. INT-174, 19 p. (18 refs.) Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.

Results of a field reconnaissance to locate problems relative to stand establishment of Rocky Mountain Douglas-fir in the Intermountain area indicate that the effects of various regeneration methods and the success expected depend largely on habitat type. Results were used to develop a research program for regeneration of Douglas-fir.

OXFORD: 236.4: 614.
KEYWORDS: regeneration survey, silvicultural systems, habitat type.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

Billings, Montana
Boise, Idaho
Bozeman, Montana (in cooperation with Montana State University)
Logan, Utah (in cooperation with Utah State University)
Missoula, Montana (in cooperation with University of Montana)
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Broadcast Burning in Larch-Fir Clearcuts:

THE MILLER CREEK-NEWMAN RIDGE STUDY

William R. Beaufait
Charles E. Hardy
William C. Fischer

FEB 6 1970

USDA Forest Service Research Paper INT-175

USDA Forest Service
Research Paper INT-153
1975

BROADCAST BURNING IN LARCH-FIR CLEARCUTS: THE MILLER CREEK-NEWMAN RIDGE STUDY

William R. Beaufait,
Charles E. Hardy,
and
William C. Fischer

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

THE AUTHORS

WILLIAM R. BEAUFAIT was graduated from Wayne State University (1949) and the University of Minnesota (1952), and holds a Ph.D. degree from the University of Michigan (1960). He spent 4 years in soils and silvicultural research in hardwoods for the Southern Forest Experiment Station, and 2 years studying the role of fire in the regeneration of northern conifers at Michigan Technological University. Dr. Beaufait was on the staff of the Northern Forest Fire Laboratory between 1962 and 1972 as a specialist in fire use. He is author of more than 30 published articles and reports. During this period he contributed to the scientific use of fire for resource management and toward understanding the role of fire in the environment. He was the principal scientist during the entire life of the study reported herein. In 1972 he became Regional Silviculturist for the Forest Service's Northern Region.

CHARLES E. HARDY was leader of the Fire Management Research Work Unit at the Northern Forest Fire Laboratory within which the study was conducted and also served on the study steering committee. He received a B.S.F. at the University of Montana in 1939 and an M.F. at the University of Michigan in 1949. Following naval duty in World War II, he served on the staffs of two National Forests and the Division of Fire Control in Region 1. In 1951 he joined the Division of Fire Research in Missoula where he conducted studies relating to fire-danger rating, prescribed fire, fire behavior, Alaskan fire problems, and fire-retarding chemicals. He has authored 18 published articles and reports. Mr. Hardy was leader of the Fire Technology Research work unit at the time of his retirement in December 1973.

WILLIAM C. FISCHER is Project Leader for the Fire Effects and Applications Research Work Unit at the Northern Forest Fire Laboratory. He conducted fuel moisture studies at Miller Creek and Newman Ridge and was responsible for collecting weather data and evaluating fire danger for the study area. Mr. Fischer holds B.S. and B.S.F. degrees from the University of Michigan.

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A study Steering Committee composed of Arthur P. Brackebusch, Charles E. Hardy, and Samuel S. Evans, Jr., provided the administrative guidance and support for this study. As Northern Region silviculturist, Evans generated much of the original impetus for this study.

Supervisors, staff officers, and rangers on the Lolo, Flathead, and Coeur d'Alene National Forests facilitated sale preparation and a rigorous harvest and treatment schedule on the study area. Ray L. Managhan and Gary L. Cain deserve special recognition for their dedcated efforts as sale administrators and burning bosses.

Cooperating scientists and technicians who participated in the study were:

Donald F. Adams, Washington State University, Air Quality Research

Curtis H. Halvorson, USDI, Bureau of Sport Fisheries and Wildlife, Wildlife Ecology Research

Norbert V. DeByle and Paul E. Packer, Watershed Management Research (INT)

Raymond C. Shearer and Robert D. Pfister, Silviculture Research (INT)

L. Jack Lyon and Peter F. Stickney, Wildlife Habitat Research (INT)

Rodney A. Norum (INT) had major responsibility for collecting and organizing much of the fire research data and provided valuable technical advice during preparation of the study report.

Patrick F. Hartless, project forestry technician, was responsible for unit layout, fuel inventory, weather measurement, and plot measurement.

Michael A. Marsden, statistician, and Roger A. McCluskey, programer, Intermountain Station, were responsible for data reduction and analysis.

ABSTRACT

Seventy-three clearcuts in western larch/Douglas-fir forests of western Montana were broadcast burned over a wide range of environmental conditions for the purpose of quantifying fire characteristics and burn accomplishment. The moisture content of the upper duff, and the National Fire-Danger Rating System Buildup Index (1964) were found to be important predictors of both the heat pulse to the site and the amount of duff removed by the fire. The same two variables along with the preburn weight of 1 to 10 cm fuels were the best predictors of the amount of fuel consumed by the fire. Associated studies are yielding information on tree regeneration, vegetal development, small mammal population dynamics, nutrient cycling, water quality, runoff and soil erosion, smoke dispersal, and convection column height--all related to varying fire characteristics and burn accomplishment.

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INTRODUCTION

As a land management tool, prescribed fire is so widely accepted and so universally practiced as to merit definition in *Forestry Terminology* (Society of American Foresters 1958): "The application of fire to land under such conditions of weather, soil moisture, time of day, and other factors as presumably will result in the intensity of heat and spread required to accomplish specific silvicultural, wildlife, grazing, or fire-hazard reduction purposes."

The use of prescribed fire for hazard reduction and seedbed preparation is a well-established management technique in northern Rocky Mountain forests (Olson and Fahnestock 1955; Roe and others 1971). Broadcast burning following clearcutting is an especially popular technique because, when successfully executed, both the fuel reduction and site preparation jobs are accomplished simultaneously.

Based on interviews with foresters throughout the Intermountain West, Beaufait (1966b) characterized a successful broadcast burn as one that: (1) consumed the duff to the extent of exposing mineral soil on 50 percent or more of the area burned, and (2) consumed all woody material up to about 6 inches in diameter.

Prescribed broadcast burns have not always accomplished these objectives. As a tool for preparing sites for future crops, prescribed fire was found to be producing erratic results in many areas of the Intermountain West, (e.g., not enough seedlings in spruce forest types, too many in larch and lodgepole). Wikstrom and Alley (1967) found a large unexplained variation in slash disposal and burning costs across the Northern Region of the Forest Service. It became important to relate such variation to silvicultural practices. The practice of clearcutting coupled with the short duration of the traditional fall burning period resulted in an increasing backlog of acres requiring postlogging treatment.

Probably the most important reason for prescribed burning failures is the variable nature of fire itself. Fire can burn over any given area in an infinite number of ways. Intensity depends on fuel volume and moisture content as well as on environmental conditions. Thus, fire is not a single treatment but rather a number of possible treatments. To be successful, the prescription and execution of a fire must be specific to a fuel bed, its moisture condition, and at least one well-defined management objective.

Prescribed fires are often scheduled during safe burning conditions for the convenience of the organization responsible for the burning. Concern is often centered on the *fact* of treatment rather than on the *quality* of treatment. Furthermore, emphasis is often placed on burning to reduce subsequent wildfire hazard, seedbed preparation being an expected side benefit. Although the wildfire hazard may be satisfactorily reduced by burning only the fine fuels, site preparation may not occur unless the heavier fuels are also burned.

The need to improve the quality of prescribed burning accomplishment was recognized by land managers and research scientists alike. Consequently, the Northern Region and the Intermountain Forest and Range Experiment Station of the USDA Forest Service jointly supported a study of prescribed fire and its use in forest management.

[illegible] *fires can be scheduled to best meet site preparation, hazard reduction, and other forest land management objectives.* The study was limited to broadcast burning of logging residues on clearcuts in the western larch/interior Douglas-fir type in western Montana.

Specific fire research objectives were:

1. Correlate a wide range of fuel and weather conditions with the amount of duff reduction and mineral soil exposure.

2. Identify and adapt (if necessary) indices of the National Fire-Danger Rating System (USDA Forest Service 1964) that characterize fuel and weather conditions that produce a burn of a specific quality.

3. Predict prescribed fire smoke column height from fuel conditions and environmental factors.

4. Provide a basic design and field layout for ancillary studies by cooperating research groups.

Ancillary Studies

One major failing of most existing fire effects literature is in adequate quantification of the fires involved. Often, fire intensity is simply characterized as being "high" or "low" based on the investigator's experience. The study design provided on unparalleled opportunity to correlate fire effects with quantified fires conducted over a wide range of fuel and environmental conditions.

Silviculture Research

Silviculturists investigated the effects of broadcast burning in larch-fir clearcuts on regeneration of western larch, Engelmann spruce, and Douglas-fir. The studies dealt with: (1) seed losses, germination, root development, and seedling survival; (2) planting stock survival and early development, and (3) the length of time the burned sites remain receptive to seeding and planting.

Watershed Research

Runoff and soil erosion studies were established (1) to determine vegetative characteristics, soil properties, topographic factors, and burning intensities that affect overland flow and erosion; and (2) to describe the overland flow and erosional behavior of larch/Douglas-fir/spruce forest land that can be predicted by forest managers. Thus, burning conditions could be identified that were best suited for site preparation and fire hazard reduction (Packer 1971; DeByle and Packer 1972).

Watershed specialists also studied the effects of burning on water quality and soil chemistry. Changes in soil fertility, quality of surface runoff water, and quality of water percolating through the soil mantle were described. Other soil properties studied were bulk density, porosity, organic matter, wettability, and nutrient content (DeByle and Packer 1972; DeByle 1973).

Wildlife Research

Wildlife habitat study plots were installed throughout the study area to describe vegetative response and to relate vegetal recovery to fire intensity.

A small mammal population study had the following objectives: (1) to measure small mammal species composition and relative abundance on uncut forest blocks, (2) to measure changes in species composition and relative abundance following prescribed burning of clearcut blocks, and (3) to describe small mammal succession after clearcutting and broadcast burning.

Air Quality Research

A three-phase field, laboratory, and theoretical study of air pollution potential was designed to identify weather conditions that would minimize pollution from prescribed fires. The study involves: (1) quantitatively and qualitatively defining the range of solid and gaseous combustion products produced by burning larch-fir slash, and (2) relating field-measured pollutants with those predicted through mechanical models of atmospheric diffusion phenomena (Adams and Koppe 1969; Flaherty 1967).

Publication of Results

This report does not attempt to document results of the ancillary studies. Much has already been published and more is forthcoming (appendix A). Smoke column height prediction at Miller Creek has been reported separately (Norum 1970, 1974). Fuel inventory techniques have also been reported in a separate publication (Beaufait and others 1974). Brown (1970) has provided a detailed report on the vertical distribution of fuel and Albini (1975) has reported on his attempt to relate heat release per unit area and duff reduction. The main purpose of this publication is to provide a project record of the Miller Creek-Newman Ridge Study. A summary report will present an integrated discussion of all that was learned during the study and will provide fire management guidelines for prescribed broadcast burning in larch-fir clearcuts.

HISTORY OF PRESCRIBED BURNING

Prescribed burning for silvicultural purposes has been a part of American forestry since the first real attempts at intensive management. Chapman (1926, 1942) is considered by many to have made the first serious application of prescribed fire in his treatments of the longleaf and loblolly pine types of Arkansas and Louisiana. Beneficial results in the form of seedbed preparation and the reduction of vegetative competition in loblolly stands were matched by the effectiveness of this tool in controlling brown spot needle blight and stimulating release from the grass stage of longleaf pine (Siggers 1934).

McCulley (1950) and Lotti (1956) expanded the use of prescribed fire in southern pine management to the southeastern tier of states and promoted the hazard reduction virtues of this technique. Thereafter, Ferguson and Stephenson (1954) found that prescribed burning in eastern Texas increased pine seedling survival and reduction competition from less valuable hardwoods.

Meanwhile, in New Jersey, Little and Somes (1949) and Little (1953) sought to perpetuate pitch, shortleaf, and loblolly pine stands in the face of encroachment by more tolerant hardwoods. By this time it had become apparent that prescribed fire was a powerful weapon with which to engage the forces of plant succession to achieve land management objectives.

In the Lake States, fire use for game habitat improvement was explored by Smith (1947), and is presently an accepted practice. Recent development of prescribed burning techniques for jack pine reproduction (Williams 1958; Chrosciewicz 1959; Beaufait 1960a) has found application in Canadian and U.S. stands of this often serotinous-coned species.

Studies of fire use for the improvement of semiarid rangelands began during the late twenties in Colorado (Hanson 1929) and southern Idaho (Pechanec and others 1954), although fire had already been employed for many years by ranchers throughout the West.

California brush ranges have been the subject of much study and controversy with regard to fire use since early in the century. Shantz (1947) summarized the past human and ecological consequences of prescribed burning in the chaparral types. Type conversion, hazard reduction, and game habitat improvement have been effected by the intelligent use of fire in California. Many of the burning techniques which have been developed as part of these programs are applicable in the Intermountain West.

Ponderosa pine stands have been burned to reduce fire hazard and vegetative competition and to prepare sites for reforestation. Beginning with the work of Pearson (1950) in the Southwest, and by Weaver (1955) in northeastern Washington, prescribed fire had passed preliminary tests as a silvicultural tool, but as yet had not been put into general practice (LeBarron 1957). Lindenmuth's (1960) survey of burning in ponderosa pine in Arizona stresses the need for more reliable means of controlling fire intensities to achieve desired objectives of fuel reduction and thinning of dense stands. Meanwhile, Morris and Mowat (1958) continued to study the aftereffects of thinning fires in Washington ponderosa pine stands, with concentration on burning procedures.

Broadcast burning of logging slash for hazard reduction and planting site preparation began as early as 1910 in the western white pine type of Idaho (LeBarron 1957). The scattered references to such practices contained no data on weather or fuel conditions until Davis and Klehm (1939) published guides for burning clearcut stands of white pine. In 1945, Lyman, concerned by the logging slash in Montana and northern Idaho, recommended greater use of fire in the treatment of slash and for converting overstocked or low quality stands of lodgepole pine and western hemlock to more valuable species.

During this time, timber management researchers in the Northern Rockies were looking to fire as a multiple-purpose tool in the treatment of problem stands. Wellner's (1946) suggestion to control *Ribes* through successive burns in cutover white pine stands has resulted in considerable burning for white pine regeneration and sanitation. Boe (1952) successfully tested fire as a regeneration method for lodgepole pine.

More recently, attention has been focused on the nature of fuels and fire itself. Measurements of slash fuels and the behavior of slash fires made by Olson and Fahnestock (1955), Fahnestock (1960), and Fahnestock and Dieterich (1962) provided a basis for quantifying potential energy sources in the use of fire for silvicultural and other land management purposes. This research compared flame height, rate of spread, and heat radiation on 0.01-acre plots with fuel loadings of 7.5, 20.0, and 32.5 tons per acre. Other forest fire researchers began characterizing natural forest fuel beds by the amount of work accomplished by prescribed fires. Using Byram's (1959) equations for energy release rate, Van Wagner (1965) compared the effects of burning 1/4-acre plots in red and eastern white pine stands at four levels of fire hazard. The latter expressed head fire intensity of each fire in a range of 20 to 370 Btu's per-second-per-foot of front and applied these data to the tree crown and stem damage, seedbed preparation, and subsequent regeneration. Van Wagner found that as fire intensity increased, both mineral soil exposure and seedling success improved. Similar results were reported by Buckman (1962, 1964) from his studies of fire's effects on hazel stems, and by Beaufait's (1960b, 1962) work with jack pine regeneration after slash burning.

Burning logging slash in the Pacific Northwest Douglas-fir region "after the duff had been soaked by rain and as soon after rain as fine fuels were dry enough to carry fire" consumed most fine fuel, left nearly all logs, and severely burned less than 6 percent of the soil surface (Morris 1970).

Earlier, Morris (1966) studied the relationship between moisture content of half-inch fuel moisture sticks and safe but effective broadcast slash burning. For coastal Douglas-fir sites, he found the significant factors to be moisture content of fuel sticks, aspect of slope, and moist/dry appearance of the lower layer of duff.

More recently, laboratory studies of fire behavior in forest fuels have laid a foundation for characterizing fires under natural conditions. Building upon the work of Thomas (1958, 1963), Rothermel and Anderson (1966) modeled mat-type fuel beds and stressed the importance of equivalent unit energy release rate in describing fire intensity and behavior.

Between 1963 and 1965, a series of 2- to 4-acre areas were inventoried and broadcast burned in Douglas-fir slash on the University of Montana's Lubrecht Experimental Forest. These tests provided: (1) a quantitative comparison of site and early vegetative succession after replicated fires in two spring and two autumn seasons, and (2) successful instrumentation for evaluating burn quality, fire intensity and spread, fuel volume and moisture content, and ignition and control methods (Steele 1964; Steele and Beaufait 1969).

A survey of prescribed burning practices in the Intermountain West identified problems encountered by forest managers. The study showed the necessity for ". . . exchange of knowledge between fire and control personnel and other specialists who use fire . . ." and the need for ". . . burning during spring and certain summer periods..." to reduce backlogs, increase acreage treated, and attain more precisely the management objectives of burning (Beaufait 1966b).

Also, in 1966, slash-fuel inventory techniques, fire characterization methods, and control methods were tested and refined in a full-scale (30-acre) broadcast burn during relatively severe August conditions on the Coram Experimental Forest.[1]

[1] Beaufait, William R. Fuels inventory for prescribed fire. (Paper presented at annual meeting of Northwest Science Association, Forestry Section, Pullman, Washington, April 1967).

PROJECT RECORD—
MILLER CREEK-NEWMAN RIDGE STUDY

Study Design

The primary fire research task was to relate burn accomplishment to fuel quantity, fuel moisture, and atmospheric situations. This problem lends itself to solution by regression analysis where a dependent variable (Y = burn accomplishment) is expressed as some function of a number of independent variables (X = fuel moisture, etc.). Inventory of fuels both before and after treatment on 7,000 points, stand examination data from 324 points, fire evaluation data from 3,600 points, weather information on 450 days, and miscellaneous inputs from subsampling problems generated over 20,000 original data cards during the course of this study. Grosenbaugh's (1967) "REX" programs were used for screening and regression analysis. A list of variables examined in regression equations and a list of all programs used and their sources are on file at the Northern Forest Fire Laboratory.

The study was designed to be as orthogonal as possible. The original plan specified: (1) an equal number of treatments in, (2) similar fuels on each of four cardinal exposures in, (3) spring, summer, and autumn, (4) over a period of 3 years, (5) on two separate experimental blocks. Complete orthogonality was not, in fact achieved. Units with heavier fuel loadings tended to be burned under conditions of higher fuel moisture than units with lighter loadings. More than anything else, this reflects a compromise between rigid adherence to experimental design and the "real world" considerations of the fire manager. A second factor affecting orthogonality was the occurrence of wildfires that burned over several units. In 1967, a wildfire at Miller Creek unbalanced the study design by burning four of six units on the same exposure.

Study Area Description

Location and Unit Layout

The study area (fig. 1) consisted of a 641-acre block located at the Miller Creek and Martin Creek Drainages of the Flathead National Forest (48°31' N. Latitude, 114°45' W. Longitude) and a 526-acre block lying on Newman Ridge between Two Mile Creek and Ward Creek on the Lolo National Forest (lat. 47°15' N., long. 115°20' W.).

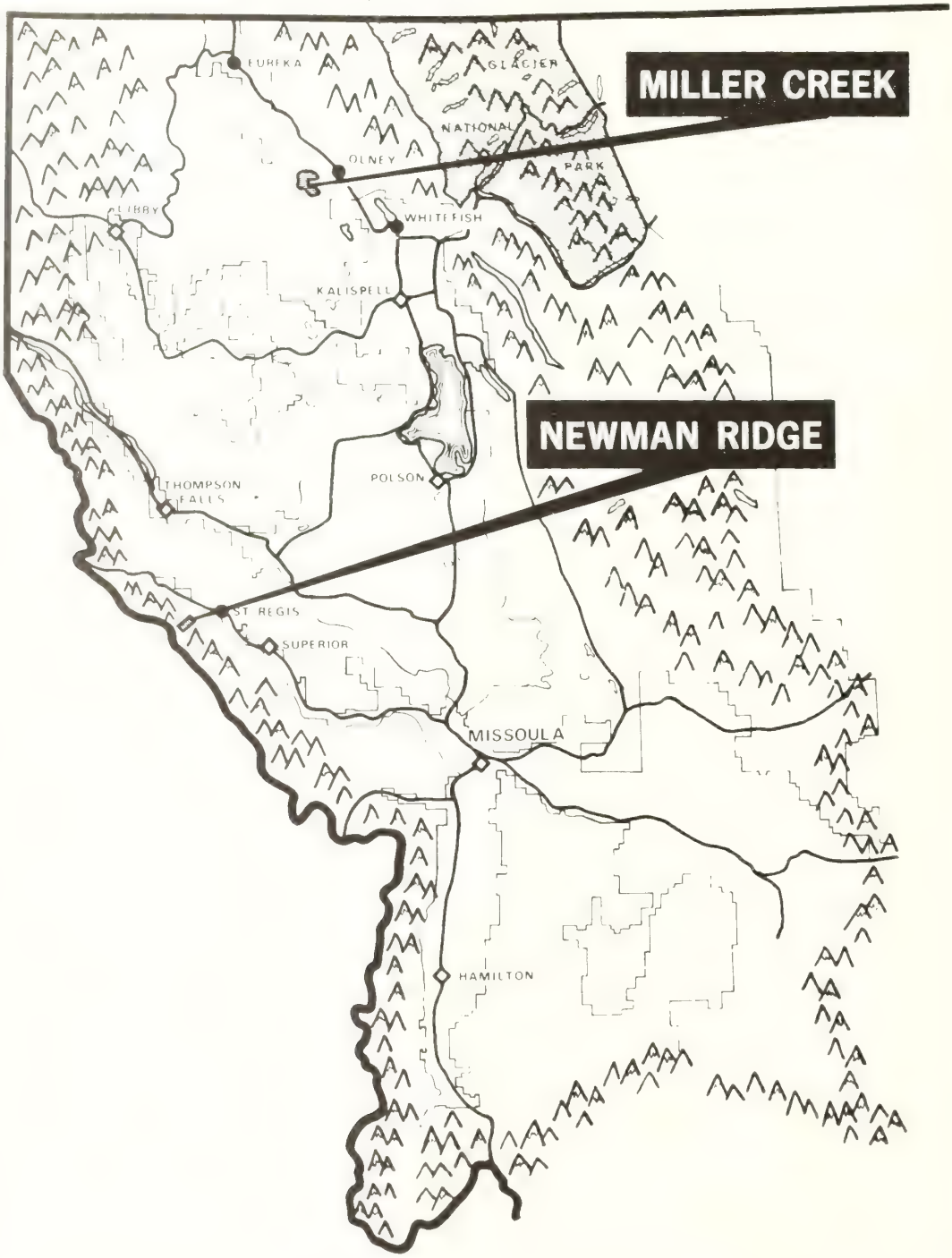


Figure 1.--Study sites on the Flathead and Lolo National Forests in western Montana.

A combined total of 76 treatment units were located on both blocks, with an equal number facing each cardinal direction. Units were first planned on aerial photographs to conform to natural topographic boundaries, with slopes and exposures as uniform as possible. The 60 units at Miller Creek (fig. 2) were square, 10 chains on a side, and included one 2-1/2-acre sample plot surrounded by a 2-1/2-chain-wide isolation strip. The 16 Newman Ridge units (fig. 3) ranged in size from 21 to 58 acres and contained three 2-1/2-acre sample plots each. Sampling points were established in each 2-1/2-acre sample plot as illustrated in figure 4.

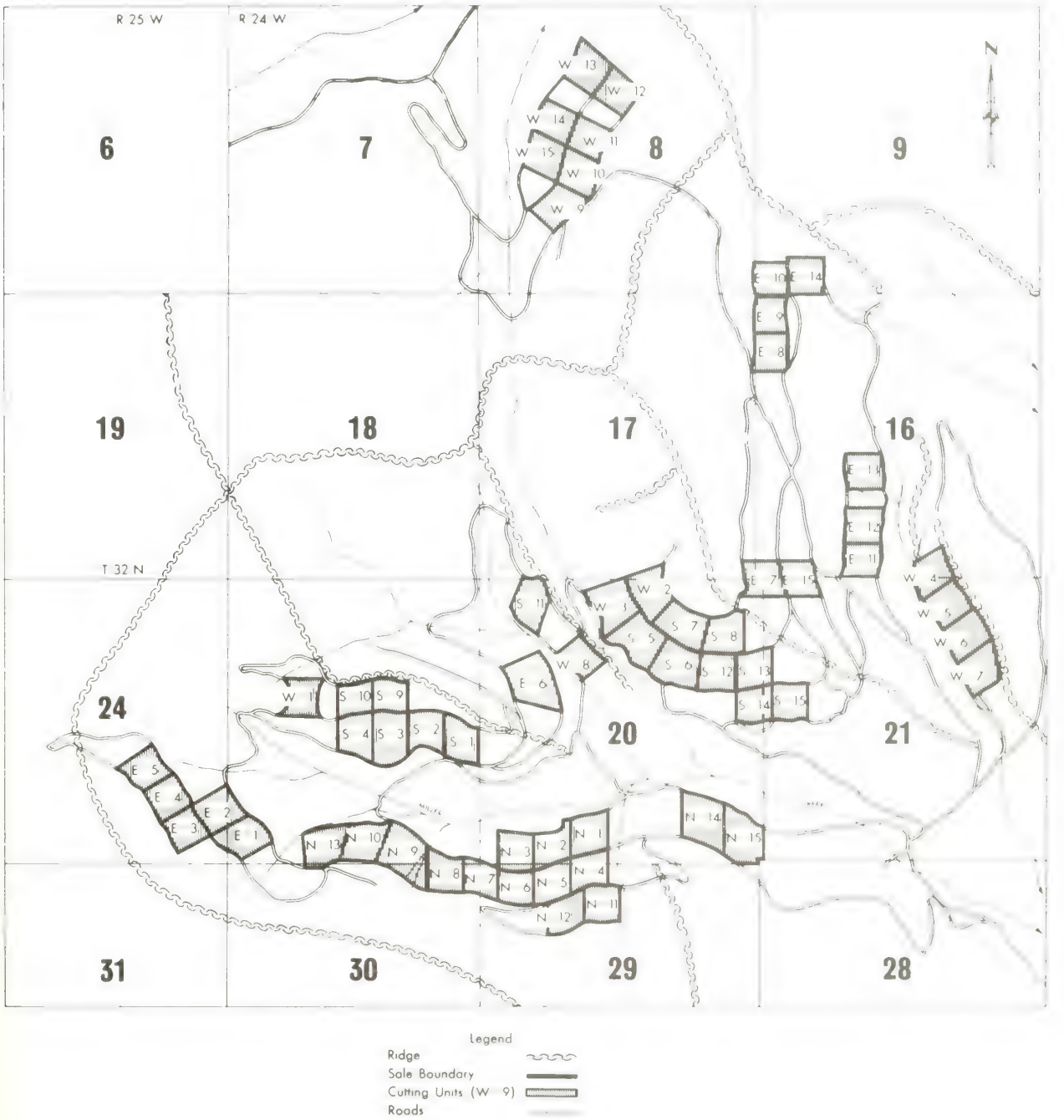


Figure 1.--Miller Creek and Newman Ridge units.

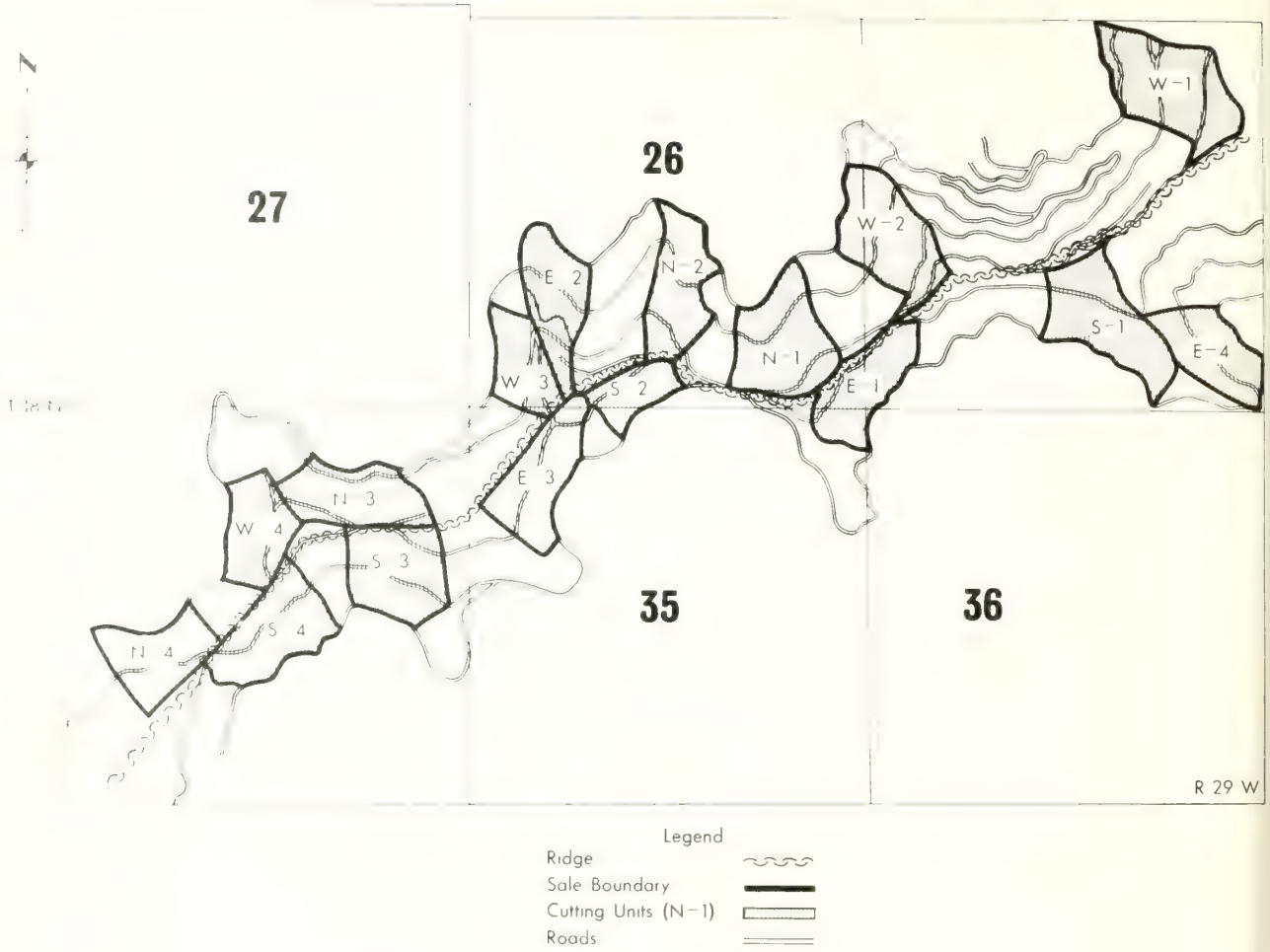


Figure 3.--Newman Ridge block unit layout

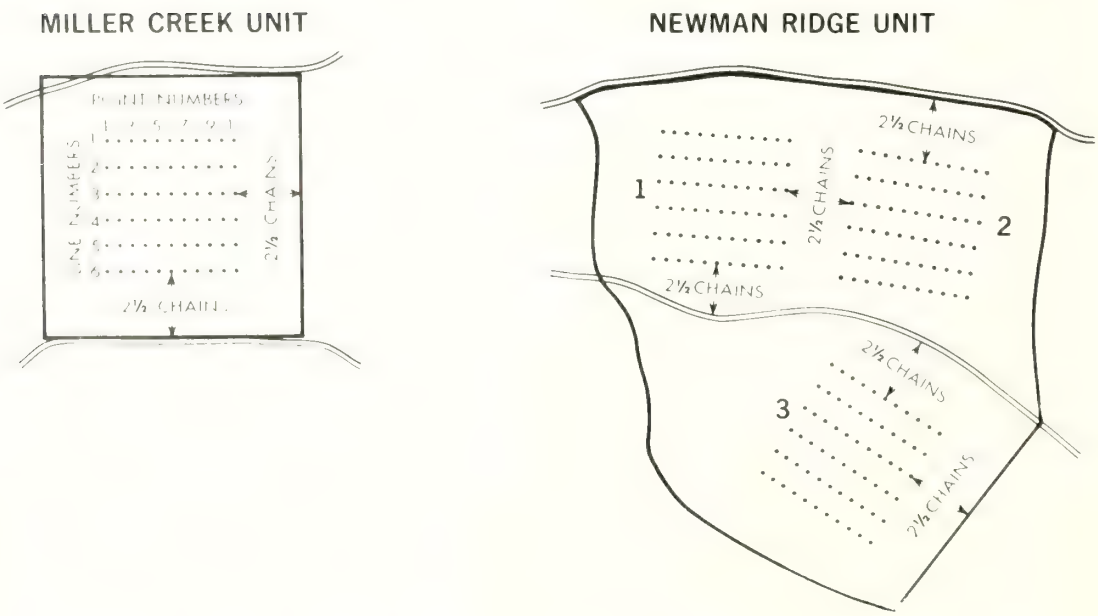


Figure 4.--Plot layout and sampling point locations on typical units.

Topography, Soils, and Climate

DeByle and Packer (1972), have described the topography, soils, and climate of the study area:

> The elevation at Miller Creek ranges from 4,200 to 5,000 feet. Slopes average 24 percent and range from 9 to 35 percent. Soils have developed in glacial till from the argillites and quartizites of the Wallace (Belt) formation and are mantled with a thin layer of loess. They belong to the Sherlock soil series and, for the most part, are Andic Cryoboralfs having an unincorporated surface organic horizon from 1 to 3 inches thick. The surface 1/2 to 1 inch of mineral soil is silt loam of single-grain structure (30 percent sand, 56 percent silt, 14 percent clay). This overlies a foot of gravelly loam with a weak blocky structure, beneath which is very stony loam to a depth of at least 6 feet.
>
> The Newman Ridge study area is slightly higher (elevations range from 4,400 to 5,400 feet) and much steeper (mean slope of 55 percent, ranging from 44 to 76 percent) than is Miller Creek. The soils have developed in place or in colluvium from argillites and quartizites of the Belt formation. The surficial loess deposit at Miller Creek is 1/2 to 2-1/2 inches thick; on Newman Ridge it is 2 to 3 inches thick. Ash from the Mt. Mazama and Glacier Peak volcanic eruptions occurs in this loess (Fryxell 1965); the remainder of the deposit probably comes from the Palouse region in eastern Washington. The texture of the surface 2 inches of soil on Newman Ridge is silt loam (29 percent sand, 58 percent silt, and 13 percent clay). These soils belong to the Craddock series and classify as Andic Cryochrepts.
>
> Miller Creek and Newman Ridge characteristically have long, cool and wet winters and short, dry summers. Annual precipitation averages about 25 inches at Miller Creek and nearly 40 inches at Newman Ridge; approximately two-thirds falls as snow. Although high-intensity summer rainstorms occasionally occur, most summer rain falls at low intensities from Pacific maritime frontal systems. The most rainfall comes during April, May, and June, the months when snowmelt runoff is greatest.
>
> Both Miller Creek and Newman Ridge can be classed as humid watershed lands, which yield more than 10 inches of stream flow annually, nearly all yearlong seepage flow (Packer 1959). When plant cover is sufficient, only a small part of the annual precipitation becomes overland flow. Most of it contributes to seepage flow or is stored in the soil mantle and thus reduces soil moisture deficits created by evapotranspiration.

Forest Cover and Habitat Types

Vegetation was classified according to forest cover type (Society of American Foresters 1967) and habitat type (Daubenmire 1952).

Cover types identified were: larch/Douglas-fir, grand fir/larch/Douglas-fir, ponderosa pine/larch/Douglas-fir, lodgepole pine, and Engelmann spruce/subalpine fir.

The larch/Douglas-fir type covered well over 50 percent of the study area. With typical variation due to exposure, Miller Creek timber volumes were evenly divided among western larch, interior Douglas-fir, and Engelmann spruce. Newman Ridge, being a bit cooler and drier, produced little spruce, but showed a greater variety of species, including some ponderosa pine and western white pine. Lodgepole pine and true firs had significant volumes in both blocks.

Figure 5.--Habitat types, Miller Creek.

Average age of Miller Creek stands was 200 to 250 years; those at Newman Ridge averaged 180 to 200 years. Table 1 summarizes the amount of commercial timber harvested from the study area.

Habitat typing on the study area represents an early extension of this technique into western Montana. The habitat type maps in figures 5 and 6 do not reflect recent refinements.[2]

[2]Pfister, Robert D., Bernard L. Kovalchik, Stephen F. Arno, and Richard C. Presby. Forest habitat types of Montana, May 1974. USDA For. Serv., Intermt. For. and Range Exp. Stn. and North. Reg.

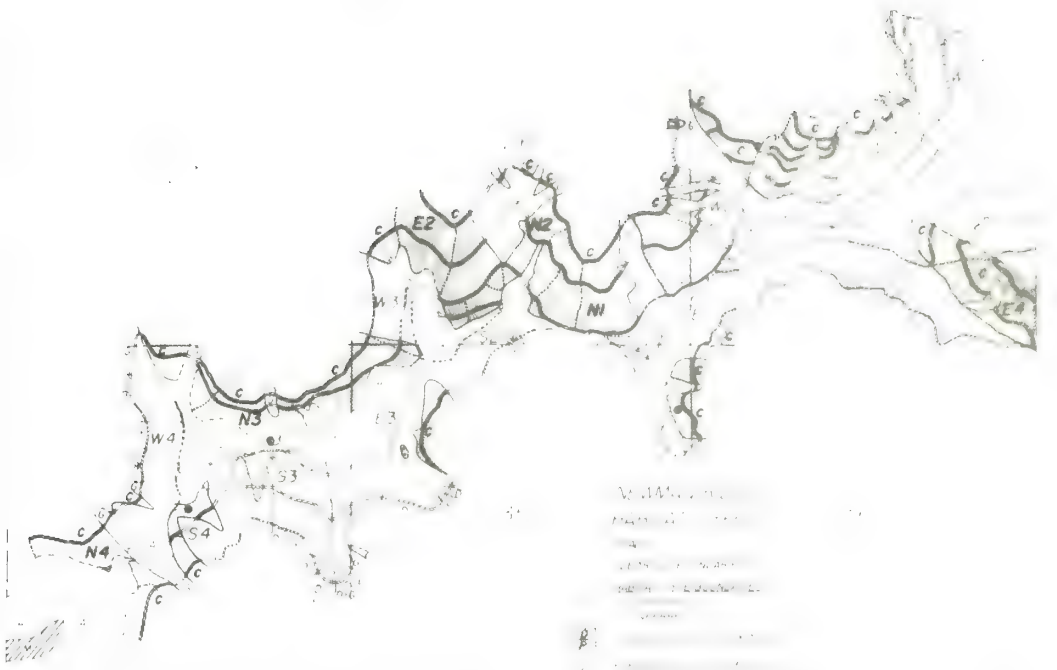


Figure 8.--Habitat types, Woman Lake.

Table 1.--

Block	Block size	Larch	Douglas-fir	True fir	Spruce	Lodgepole pine	Ponderosa pine	White pine		
North	162	7.7	9.6	1.4		2.1	1/			
East	162	7.1	4.4		11.4					
South	159	4.7		1.4	2.6	.1				
West	158	6.3		1.0		1.0				20.1
Block total or average	641	6.4	7.5	1.6		1.5	-			
Percent of volume by species	--	25.7	30.6	6.5	31.1		-			
North	129	7.0		1.3	.1	2.9		1.0	0.6	
East	109	4.9		5.0	2.1					
South	137	3.6								
West	151	5.1		1.0						
Block total or average	526	5.1		1.4			1.7	1.1		
Percent of volume by species	--	26.4	33.6			16.9		2.8	1.4	100.0

1/ Indicates no significant volume

Miller Creek units occurred primarily within the *Abies lasiocarpa/Pachistima myrsinites* habitat type (fig. 5). Two distinct phases were recognized in addition to the generic type. A *Xerophyllum* phase occurred on most south- and west-facing slopes, and a *Menziesia* phase on north exposures. Stream bottoms supported the *Thuja plicata/Pachistima myrsinites* habitat type.

Seven habitat types were recognized on the Newman Ridge area, *Abies grandis/Pachistima* and *Thuja Plicata/Pachistima* habitats predominating (fig. 6). The former occupied concave east, northwest, and protected south slopes; the latter were found on concave north and northeast slopes. Ridges were occupied by either *Abies lasiocarpa/Pachistima* if north-facing, or *Abies lasiocarpa/Xerophyllum* if south-facing. The driest and warmest sites supported the *Pseudotsuga menziesii/Physocarpus* habitat type, while *Pseudotsuga menziesii* appeared on the driest and coolest sites. *Tsuga mertensiana/menziesii* occupied the highest elevations at Newman Ridge.

Fuel Conditions

Logging slash constitutes an extraordinary wildfire hazard soon after it is created. If the trees are felled in summer, 4 to 12 weeks are needed for slash up to 10 cm (4 inches) in diameter to be cured and reach moisture equilibrium with its environment (Olson and Fahnestock 1955; Fosberg 1970). The slash from stands cut in autumn or winter often retains its moisture until the following summer. Needles and fine twigs reach equilibrium much more quickly than the larger slash particles.

Fire managers prefer to burn slash within a year following logging, not only to reduce the fire hazard but to obtain other benefits. Slash burned soon after curing retains needles that promote the ignition and spread of broadcast fires. Slash that burns readily can be burned under a wide variety of weather conditions, is easier and cheaper to burn, and offers considerable flexibility in preparing a site for reforestation.

The study design called for burning of all exposures in spring, summer, and autumn over a 2-year period at Miller Creek and 1 year at Newman Ridge. The three-season spread had two purposes: (1) to sample soil and fuel moisture relationships throughout the snowfree season to determine their effect on burn accomplishment, and (2) to study the effects of burning on plants (both tops and root systems) at different stages of growth and maturity. Superimposing these goals on the constraints outlined in the preceding paragraph made for an ambitious schedule that was not entirely met. Experimental design also required that fuel beds be as uniform as possible in order to eliminate fuel continuity as a variable and to enhance fire spread across the unit. This was accomplished by requiring directional felling and double drum jammer skidding. Jammer roads were spaced at least 600 feet apart. All machine operation was strictly forbidden within the 2-1/2-acre sample plots. Whenever possible the uniformity of the fuel bed was enhanced by the slash crew during slashing and laydown of unmerchantable stems. Fire breaks (dozer-blade-wide) were dozed along all sides of each unit not bordered by a jammer road.

Anticipated fire behavior was the main consideration in determining if a unit was ready to burn. Fuel moisture had to be within a range where the fire could be expected to burn the entire unit. Weather had to be favorable enough to keep a fire within the designated unit.

Fuel moisture and fire weather were continuously monitored to provide information needed to evaluate a unit's readiness to burn. Weather stations were located at Miller Creek and Newman Ridge close to the clearcut units (fig. 7). Companion stations were

also located in nearby valley bottoms to identify nighttime temperature inversions, an important influence on nighttime fire behavior. Fire weather stations were operated in accordance with standard procedures (Fischer and Hardy 1972). A hygrothermograph modified to record windspeed as well as temperature and humidity (Fischer and others 1969) proved to be especially useful in identifying favorable burning conditions (Beaufait and Fischer 1969).

In the western United States, moisture content of indicator sticks is a commonly used method for scheduling broadcast burns (Morris 1966). Standard 100-gram fuel moisture indicator sticks were installed early each season at weather stations on the study area and at units scheduled for treatment that year. Sets of fuel moisture sticks, placed at standard 10-inch height (without screens) were paired with others in adjacent uncut timber with the same slope and exposure. Sticks were weighed periodically throughout the season and immediately prior to burning.

Constraints on ignition procedures were: (a) a central and single convection column must be obtained and maintained to expedite firing and to enhance safety; (b) the 2-1/2-acre research plot would be burned by a heading fire to insure uniformity of treatment.

Specific firing plans considered [illegible] weather, and location relative to other units. Usually, a unit was first ignited along a line about 1 chain below its uphill edge, often by remote ignition. The uphill edge was ignited as the fire front approached it and then the unit sides were ignited. Finally, the lower edge was ignited to produce a heading, uphill fire over most of the area (fig. 8).

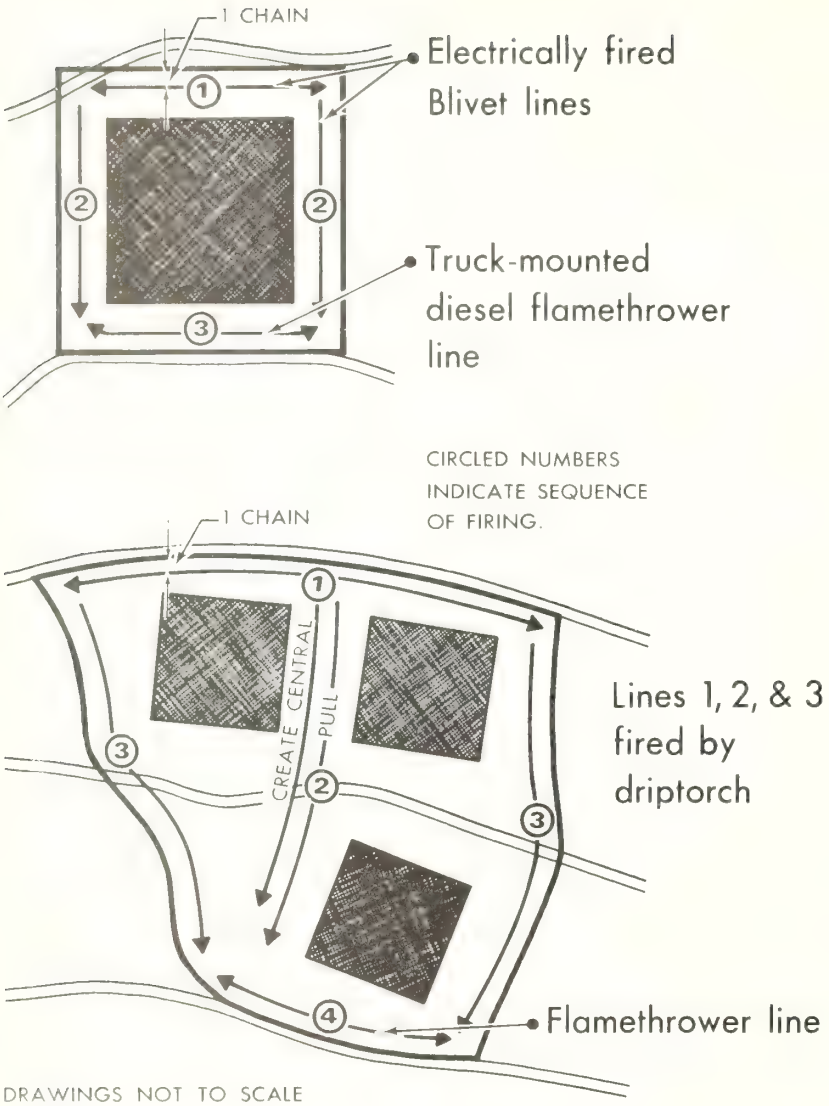
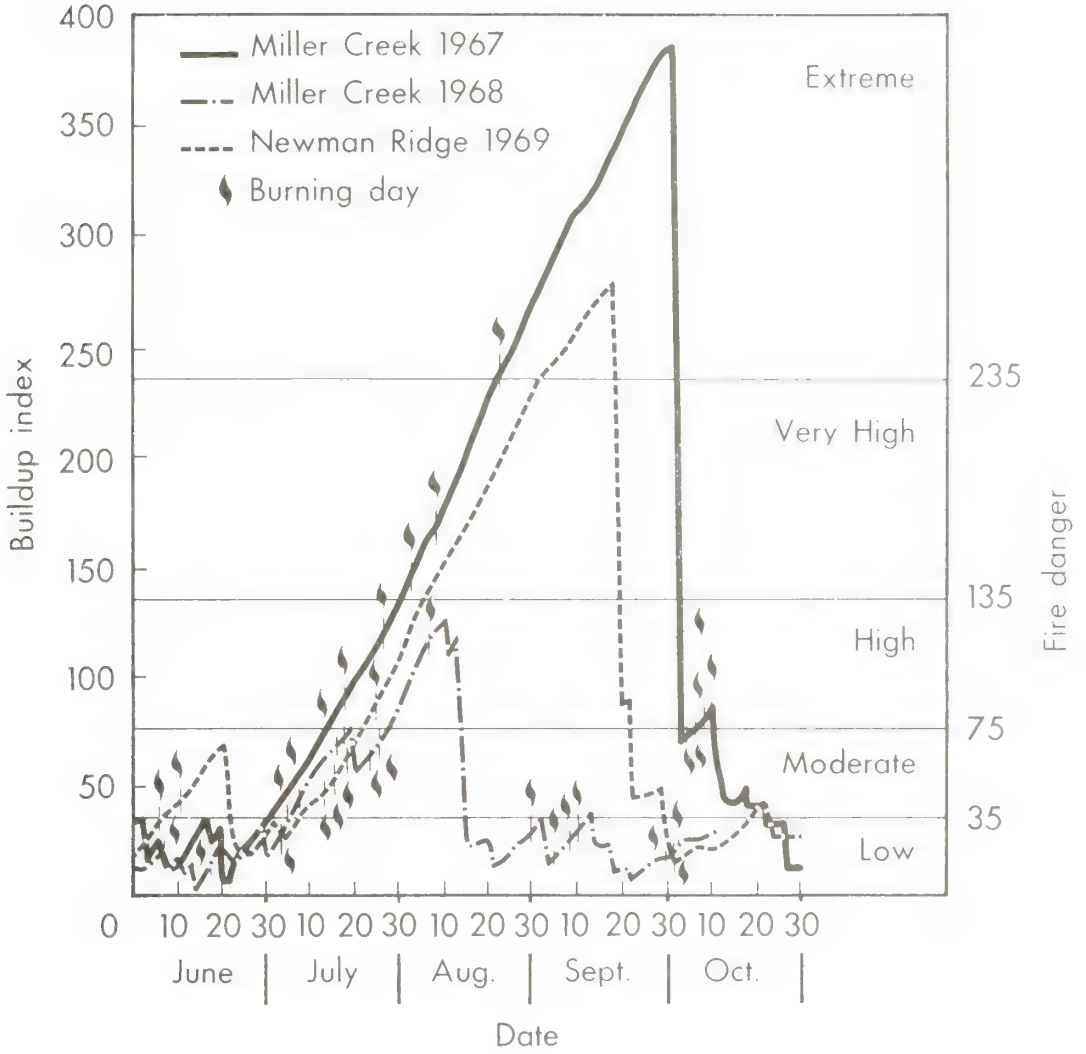


Figure 8.--Typical firing patterns for Miller Creek (above) and Newman Ridge units.

Most of the fires were ignited in late afternoon, or in the evening after winds ceased but before humidity started to rise (Beaufait and Fischer 1969). Firing was generally completed within 20 minutes on the 10-acre Miller Creek units. It sometimes took as long as 40 minutes to ignite the much larger Newman Ridge units.

The timber harvest and fire treatment schedule is detailed in appendix B. A total of 73 sample plots in 55 different units were treated. Three sample plots were burned in the spring, 54 in the summer and 16 during the autumn. The treatment record over the 3 years probably represents the realistic range of prescribed burning opportunities in the northern Rocky Mountains.

Figure 9 displays burning conditions during the 3-year study period based on the National Fire-Danger Rating System Buildup Index (USDA Forest Service 1964). Buildup index indicates overall severity of burning conditions (Fischer 1969). Figure 9 also reports the range of burning conditions sampled. Periods of "Very High" and "Extreme" fire danger were considered too dangerous for prescribed burning.



at Miller Creek and Newman Ridge.

Fuel Inventory Methods

Fire intensity varies with, among other factors, the moisture content, size, and distribution of fuel particles. Slash lies in a porous bed of roughly horizontal branches, tops, and unmerchantable stems. This admixture is complicated by a range of species, utilization standards, skidding practices, and site characteristics. Slash, in turn, lies atop a mat-like organic mantle on the forest floor, the "duff" (often broken into three components--litter, duff, and decomposed humus).

After harvesting and slashing had been completed, the fuel complex on each unit had to be described by means of a method that would compare fuels before and after burning. Data were collected from approximately 7,000 systematically placed meter-long transects (66 per 2-1/2-acre plot) on both experimental blocks (fig. 4). Data included the number of woody intercepts by species and size class (< 1 cm, 1 to 10 cm, and > 10 cm), depth of slash bed, depth of organic duff, slope and exposure, and ground cover.

In addition to recording woody intercepts, slash was subsampled to determine:

a. average diameter of intercepts by species and size classes < 1 cm and 1 to 10 cm.

b. actual diameter (to nearest 10 cm) of stems > 10 cm,

c. the number, weight, volume, and surface area of leaves on twigs < 1 cm in diameter,

d. probability proportional to prediction (3P) on estimates of < 1 cm material,

e. ratios of duff dry weight to depth, and

f. bulk density or specific gravity of all fuel components.

Much of the data collected by subsampling was used in conjunction with the transect data to compute fuel loadings. Data on fuel surface area was used as an independent variable in fuel reduction regressions. Table 2 summarizes, by species, data collected by subsampling fuels.

Table 2.--*Fuel physical data (mean diameter, specific gravity, conversion ratios)*

Fuel parameter	Species								
	Ponderosa pine	Douglas-fir	Larch	Lodgepole pine	Spruce	True fir	Cedar	Yew	Hardwoods
0 to 1 cm mean diameter (cm)	0.69	0.20	0.26	0.42	0.20	0.24	0.32	0.12	0.18
1 to 10 cm mean diameter (cm)	2.92	3.05	3.03	3.87	2.19	2.30	2.26	2.50	2.50
Specific gravity needles	.51	.56	.62	.56	.56	.52	.41	.52	.56
Specific gravity 0 to 1 cm	.41	.55	.46	.49	.34	.41	.48	.50	.45
Specific gravity 1 to 10 cm	.51	.43	.55	.41	.34	.40	.33	.55	.45
Specific gravity 10 to 90 cm	.51	.43	.55	.41	.34	.40	.33	.55	.45
Needle weight to branch weight ratio	2.52	1.18	.27	1.03	1.36	1.42	2.08	.76	1.09
Needle surface to volume ratio	57.6	69.1	184.0	64.7	54.2	69.1	80.5	69.1	85.0

Ratios of dry weight to depth were used to develop regression equations for predicting duff weight from pre- and postburn measurements of duff depth. The equations developed are as follows:

	MILLER CREEK	*NEWMAN RIDGE*
North units	$\hat{Y} = -10.41 + 12.98X$	$\hat{Y} = 12.96 + 8.17X$
East units	$\hat{Y} = 15.33 + 13.72X$	$\hat{Y} = 5.01 + 11.12X$
South units	$\hat{Y} = 13.49 + 9.16X$	$\hat{Y} = 17.26 + 7.24X$
West units	$\hat{Y} = -5.42 + 13.69X$	$\hat{Y} = 6.39 + 11.17X$

Where: $\hat{Y}$ = predicted duff weight (gms in a 5-inch cylinder)

X = measured duff depth (cms)

These equations give the predicted weight in a 5-inch-diameter soil sample cylinder. We multiplied Y value by 0.352217 to obtain duff loadings in tons/acre (by 0.078976 to get kg/m^2).

Fuel inventory techniques used in this study have been reported by Beaufait, Marsden, and Norum (1974). Since this pioneering attempt, fuel inventory techniques have been refined. Recent work by Brown (1974) describes current methodology.

Fuel Loads

Preburn fuel loads, exclusive of duff, varied from 60 to 165 tons/acre (14 to 37 kg/m^2) among individual units. When grouped by exposure, however, the average loadings showed remarkable uniformity (table 3). Miller Creek units supported slightly higher slash loadings than those at Newman Ridge: 114 tons/acre compared to 104 tons/acre (25 kg/m^2 vs 23 kg/m^2). Size distribution within units was also quite similar. Approximately 88 percent of the slash fuel weight, exclusive of duff, was accounted for by material greater than 10 cm in diameter; 10 percent by material 1 to 10 cm in diameter; and 1 percent each for twigs (0 to 1 cm in diameter) and needles.

Table 3.--*Summary of preburn fuel loads by exposure and size class for two areas*

Exposure	Duff		Needles		Down and Dead Stem and Branchwood Components						Average load
					0 to 1 cm		1 to 10 cm		>10 cm		
	Mean weight	Std. dev.	Mean weight	Std. dev.	Mean weight	Std. dev.	Mean weight	Std. dev.	Mean weight	Std. dev.	
					MILLER CREEK						
North	21.75	8.20	1.66	0.42	1.33	0.34	8.92	3.35	107.84	21.18	141.50
East	41.13	7.08	1.64	.32	1.38	.24	11.61	3.05	94.91	18.62	150.67
South	23.81	3.34	1.36	.33	1.17	.21	10.24	2.66	107.55	28.81	144.13
West	18.65	7.70	1.48	.44	1.26	.37	8.57	3.14	94.77	23.29	124.73
Block average	26.34	10.09	1.54	0.14	1.29	0.09	9.84	1.38	101.27	7.42	140.26
					NEWMAN RIDGE						
North	27.03	2.58	1.39	0.55	1.06	0.24	8.56	1.31	94.76	16.21	132.82
East	19.07	3.54	1.00	.47	.83	.27	9.10	2.55	86.10	15.59	116.10
South	23.09	1.29	1.78	.66	1.36	.29	12.99	4.82	83.17	15.00	123.39
West	22.20	4.44	1.39	.63	1.20	.34	12.22	4.07	97.81	14.93	134.82
Block average	22.86	3.30	1.39	0.32	1.11	0.22	10.72	2.21	90.46	6.94	126.54

Table 4.--*Average duff depth by exposure*

Exposure	Miller Creek		Newman Ridge	
	Mean depth cm	Standard deviation	Mean depth cm	Standard deviation
North	6.43	1.48	6.24	0.90
East	6.27	1.47	5.77	.90
South	4.43	1.04	4.35	.42
West	4.66	1.60	4.50	1.13
Block average	5.45	0.91	5.22	0.93

Brown (1970) investigated the vertical distribution of fuel particles in the slash at Miller Creek. He found that about 68 percent of both the fuel volume and fuel surface area was concentrated in the lower portions of the slash (i.e. below the average mid-depth of the slash).

In the Miller Creek slash, Brown (1970) also noted a high frequency (40 percent of transects) of needle mats caught on branches.

Duff weight on individual units varied between 4 and 50 tons/acre (0.90 and 11 kg/m^2) at Miller Creek and between 15 and 29 tons/acre (3 and 7 kg/m^2) at Newman Ridge. Average duff weight for Miller Creek units was about 26 tons/acre (5.9 kg/m^2) compared to about 23 tons/acre (5.1 kg/m^2) for Newman Ridge units. Duff depth averaged 5.45 cm at Miller Creek and 5.22 cm at Newman Ridge. North and east exposures supported deeper duff on the average than did south and west exposures (table 4).

Preharvest stand examination procedures commonly used in the Northern Region (USDA Forest Service 1965) were modified to include collection of additional data on standing and down sound and dead trees, duff depth, and ground cover vegetation. The expanded stand examination data was then correlated with the fuel inventory to test the feasibility of predicting fuel loads that would result from clearcutting in larch/fir. The attempts failed because sampling was insufficient to account for natural variation and because crown weight data were inadequate. Current work by Brown[3] will result in a much improved capability for such predictions in the near future.

Fuel Moisture

Moisture contents of various components of the fuel complex were utilized as independent variables in burn accomplishment regression equations. Samples of needles, twigs, and branches were collected from several heights within the slash over each of three sample points within each unit. Samples of litter and duff were also collected at each sample point. Sampling was always done just before burning.

[3]Brown, James K. Prediction of tree crown weights and size distribution of crown components. Study Plan 2104-17 on file at the Northern Forest Fire Laboratory, Missoula, Montana.

Methods for determining moisture content varied with the size and wetness of the samples. Small, relatively dry material was ground in an intermediate Wiley mill and evaluated titrimetrically using Karl Fischer reagent. Large, moist, samples were weighed before and after ovendrying at 105° C.

A range of preburn fuel moisture conditions were measured on each of the four exposures, as indicated by the average values shown in appendix C. Replication of similar moisture conditions both within each exposure as well as between exposures was also achieved. Similar fuel moisture conditions occurred throughout the 6-month period in which burning was accomplished (appendix D).

Range and frequency of moisture content of various fuel components are illustrated in figure 10. The upper duff exhibited the widest range of fuel moisture of any of the components sampled. As will be seen later, upper duff moisture content proved to be an important predictor of burn accomplishment. Although litter exhibited a fairly wide range of moisture retention, moisture content was 5 percent or less on half the units burned. The larger twig and branch components displayed a more uniform frequency of moisture content than the duff and litter but over a narrower range of moisture conditions.

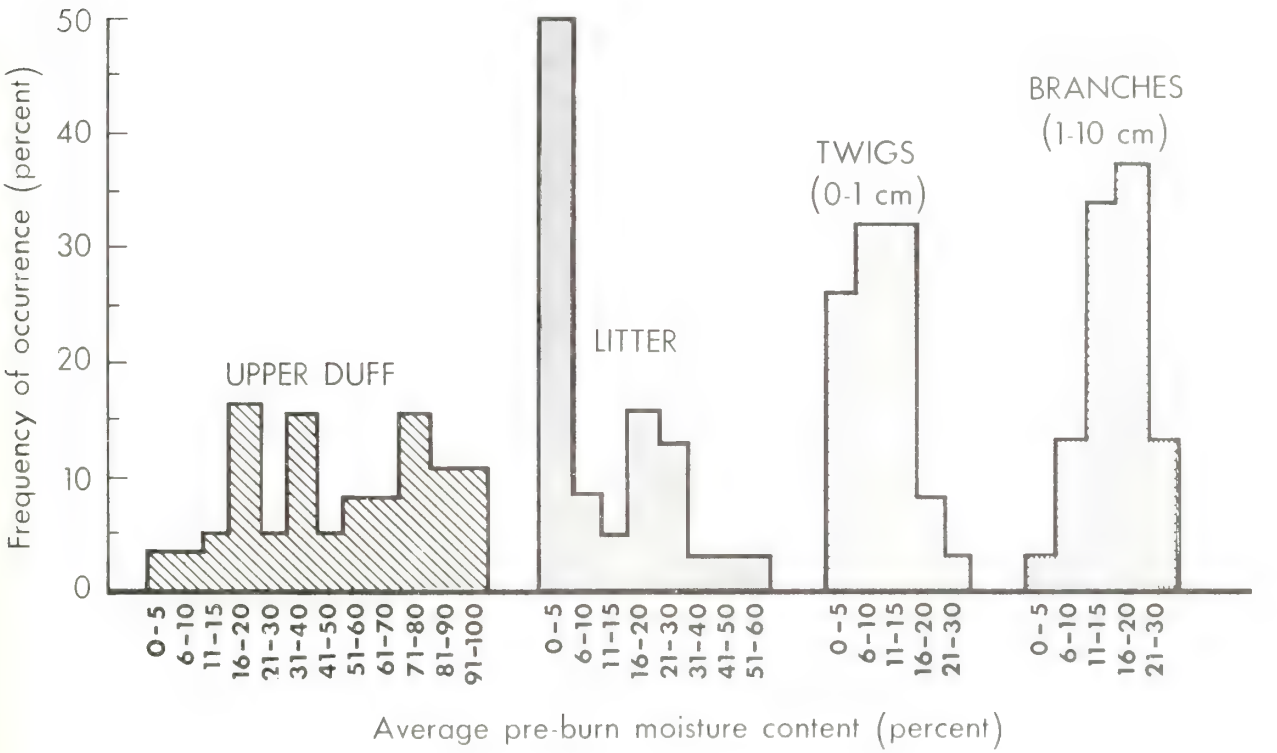


Figure 10.--Range and frequency of preburn moisture content for four fuel bed components.

Attempts to Predict Fuel Moisture

In actual practice, land managers seldom measure fuel moisture directly but instead rely on predictions from indicator sticks or fire-danger rating systems. Consequently, current fire-danger moisture indices were calculated and examined along with other independent variables in burn accomplishment regression equations. Moisture indices tests were Buildup Index (BUI), Fine Fuel Moisture (FFM) and Adjusted Fine Fuel Moisture (AFM). All of these indices were components of the Spread Phase, National Fire-Danger Rating System (USDA Forest Service 1964). All are calculated from various combinations of temperature, relative humidity, and precipitation observed at on-site weather stations. Because their use was not included in the then current fire-danger rating system, indicator stick data was not included in burn analysis.

The predictive capability of indicator sticks and fire-danger rating indices was also evaluated by comparing their values with laboratory determined moisture content. Table 5 shows the results of this evaluation. Buildup Index showed a fair to good correlation with measured moisture content of the duff under standing timber. Fine Fuel Moisture and Adjusted Fuel Moisture values did not relate very well to actual moisture content of needles on or in the duff. The moisture content of 1/2-inch fuel moisture sticks showed better correlation with needle moisture than did any of the fire-danger indices.

Table 5.--*Simple linear correlation coefficients between actual litter and duff moisture content and predictors of fuel moisture*

Predictor	Moisture content		
	Litter	Upper half of duff	Lower half of duff
	Coefficients of determination (R^2)		
NFDRS Fine Fuel Moisture	0.31	0.30	0.27
NFDRS Adjusted Fuel Moisture	.46	.51	.49
NFDRS Buildup Index	.37	.63	.74
1/2-inch ponderosa pine fuel moisture sticks	.55	.36	--

Burn Evaluation

Burn evaluation was guided by the study objectives, which in turn were a reflection of management needs. Consequently, it was imperative to quantify burn accomplishment in terms of duff reduction and fuel loss, and to characterize the experimental fires in a way that allowed a ranking of relative fire intensity. Fire effects could then be evaluated in terms of the character (cool vs hot) of the fires. To this end, water can analogs were used to obtain a value for heat pulse to the site. Several other methods of evaluating fire intensity were also explored but proved less productive.

Regression equations presented here summarize recent experience with slash burning and its direct effects in the western larch/interior Douglas-fir forest type in Montana. The equations describe the relationships among fire accomplishments, fuel, and weather. The equations are not predictive statistically but are applicable to large areas in the northern Rocky Mountains where vegetative and topographic characteristics are similar to the study area.

Although the organic mantle on the forest floor may appear uniform and uniform on its surface, it is uneven along its contact with mineral soil. Buried, partly decomposed stems and stumps are often interspersed with rocks protruding into the duff. The irregularity of this inorganic-organic interface often complicates attempts to describe duff depth before burning and duff loss from a fire.

Changes in the duff mantle due to burning were measured as follows: (1) direct measurement of depth during preburn and postburn fuel inventories, and (2) installation of spikes in the soil before burning, with subsequent recording of changes in the duff level. In the former method, the duff depth was measured at three points along each of the 66 1-meter-long fuel inventory transects on all plots. The average depth per transect was recorded to the nearest centimeter in the fuel inventory. This process was repeated after burning, and the average loss per plot computed.

In the latter method, large spikes (8-inches long) were driven into the soil until the heads were flush with the surface of undisturbed preburn duff (fig. 11). Spikes were located 1/2-meter on either side of each inventory point. After each fire, ashes were blown away from the spikes and the exposed spike length was recorded. In this way, preburn and postburn duff depths were observed on identical points. These data also served as dependent variables in the duff reduction analyses, and also as dependent variables in the analysis of fire effects.

Heating may cause temporary swelling of duff and consequently overestimation of depth; therefore, postburn depth was measured after precipitation washed the ashes away and resettled the duff.

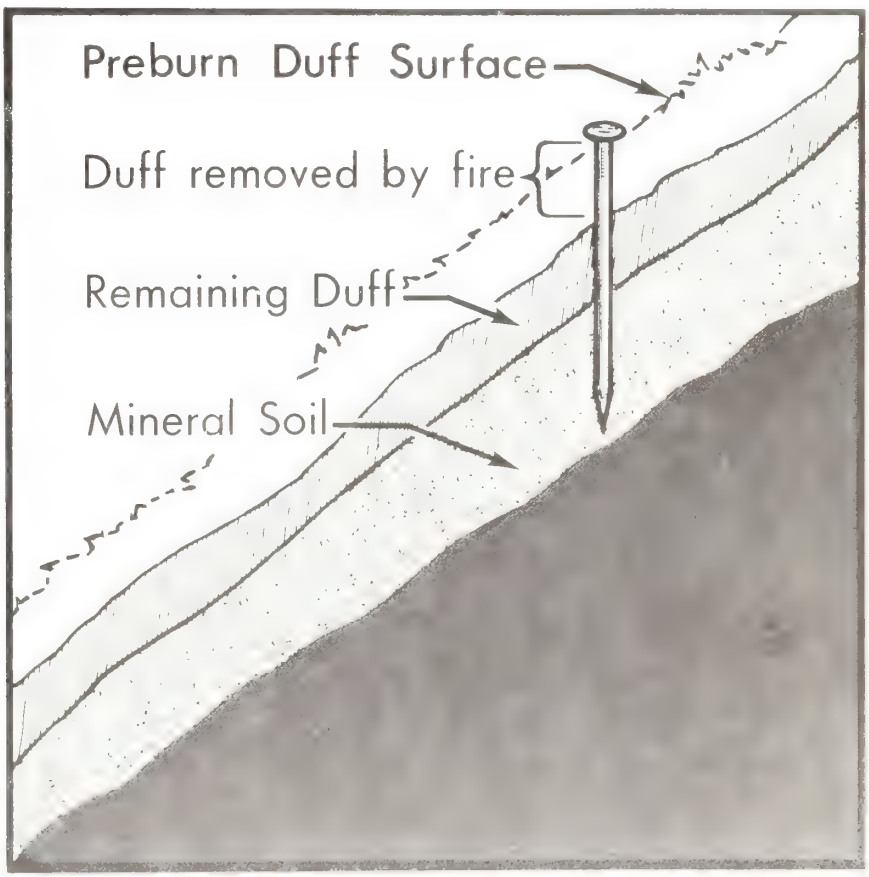


Figure 11.--Spike installation to determine duff reduction.

The original study plan called for expressions of fire's direct effect both through actual duff removed and the percentage of mineral soil exposed. Of these two variables, duff loss measurements obtained from the spikes proved to be most reliable. Although mineral soil exposure was recorded at the same time as duff depth (preburn and postburn fuel inventories), internal plot variability obscured slight changes that may have occurred in the percentage of exposed mineral soil in postburn transects.

The equation describing actual reduction in duff depth by broadcast burning quantifies the obvious--the drier the fuel, the deeper the burn. Two different expressions of duff moisture were used as independent variables: (1) Buildup Index (BUI) and (2) measurement of moisture content.

The equation of best fit for duff depth reduction was:

$$Y(2) = f\left(X(2), X(7), X(12)\right)$$

$$Y(2) = \left(1.0719 - 0.0161X(2) + 0.05215X(7) + 0.0740X(12)\right)$$

Where:

Y(2)	Duff depth reduction	0 to 6.1 cm		
X(2)	Upper duff moisture content	7.5 to 99+ percent	4.5	99.9
X(7)	Buildup Index	15 to 237	5.1	99.9
X(12)	$\sqrt{\text{Buildup Index}}$		6.8	99.9

Standard error of regression = 0.801 cm

"F" = 46.7 (with 1 and 60 degrees of freedom)

$F_{(1, 60, .01)} = 5.65$

Additional variables tested:

X(1) = needle moisture content

X(3) = slash depth

X(4) = 1 to 10 cm fuel weight

X(5) = adjusted fine fuel moisture

X(6) = lower duff moisture

X(8) = 1/weight of 1 to 10 cm

X(9) = 1/fine fuel moisture

X(14) = 1/X(5)

Table [illegible] 1/

Upper duff moisture content (Percent)	Buildup index									
	10	35	60	85	110	135	160	185	[illegible]	[illegible]
5	2	3	3	4	[illegible]	6	[illegible]	[illegible]	[illegible]	[illegible]
10	1	2	3	4	5	[illegible]	[illegible]	[illegible]	10	10
15	1	2	3	4	5	6	[illegible]	[illegible]	10	10
20	1	2	3	4	5	6	[illegible]	8	[illegible]	[illegible]
25	1	2	3	4	5	6	[illegible]	8	[illegible]	[illegible]
30	1	[illegible]	[illegible]	4	5	6	[illegible]	[illegible]	8	[illegible]
35	1	2	[illegible]	[illegible]	5	[illegible]	[illegible]	[illegible]	8	[illegible]
40	1	2	[illegible]	4	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
45	1	[illegible]	[illegible]	4	5	6	[illegible]	[illegible]	[illegible]	[illegible]
50	1	2	[illegible]	4	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
55	1	[illegible]	[illegible]	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60	1	[illegible]	[illegible]	4	[illegible]	5	[illegible]	[illegible]	[illegible]	[illegible]
65	1	[illegible]	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
70	1	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
75	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
80	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
85	0	[illegible]	2	3	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
95	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
100	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

1/ Approximate range of collected data [illegible]

Table [illegible] contains solutions of the equation of best fit for various [illegible] of duff moisture and Buildup Index. This table can be used to estimate duff reduction for sites and treatments similar to those studied. The table also reflects that the accumulated dryness variable, represented by the Buildup Index, becomes increasingly important as duff gets deeper.

[illegible]

Fuel loss was evaluated by reinventorying fuels after each fire. Meter-long transects at random angles from the contour were installed at the same points used for preburn fuel inventory. Table 7 summarizes preburn and postburn fuel inventories. Preburn fuel weights reflect loadings prior to burning. Because some plots were not burned or were lost in wildfires, in some cases these values differ from those listed in table 5.

Pre- and postburn fuel sampling intensity was based on the erroneous assumption that the fuels larger than 10 cm are generally not consumed by prescribed fires; consequently, fuels larger than 10 cm were sampled less intensely than those smaller than 10 cm. As a result of this sampling error, inventories of material larger than 10 cm are only suggestive of actual volumes contained in that size class. Therefore, in this report fuel loss mainly includes: (1) leaves suspended on slash, (2) twigs < 1 cm in diameter, and (3) branches 1 to 10 cm in diameter.

Table 7.--*Fuel quantities before and after broadcast burning*

Fuel size	Miller Creek[1]			Newman Ridge[2]		
	Preburn quantity	Quantity burned	Percentage burned	Preburn quantity	Quantity burned	Percentage burned
	tons/acre			*tons/acre*		
Needles	1.54	1.54	100.00	1.56	1.56	100.00
0 to 1 cm	1.29	1.12	87.00	1.14	1.05	92.00
1 to 10 cm	9.84	6.78	69.00	12.10	10.62	88.00
Subtotal	12.67	9.44	75.00	14.80	13.23	89.00
10 cm	101.27	59.60	60.00	93.49	51.66	55.00
Total	113.94	69.04	61.00	108.29	64.89	60.00

[1] Average of 41 plots.
[2] Average of 24 plots.

Analysis of the fuel loss data indicates that regardless of fuel loading, burning condition, or aspect, the percentage of fuel consumed is in inverse relation to its size (table 7). An acceptable fuel loss equation was not derived because of treatment bias between fuel loadings and fuel moisture content. The equation is reported here only to illustrate the probable sources of bias. Bias was caused by a natural tendency to burn units having large amounts of fuel under relatively safe fire-weather conditions. Thus, units with light loads were left to be burned during the more severe conditions. Reinforcing this tendency is the fact that heavier fuels generally occur on cool, moist, north and east exposures. By the same token, light fuels generally occur on more severe south and west exposures where moisture contents are generally lower.

The equation of best fit for fuel weight loss is:

$$Y(4) = f\,X(4), X(7), X(11)$$

$$Y(4) = -258.57 + 0.8651X(4) - 2.629X(7) + 4{,}540.8X(11)$$

where:

Variable	*Description*	*Range*	*"t"*	*Level of significance (percent)*
Y(4)	Fuel weight loss, 0 to 10 cm and needles	0.289 to 4.30 kg/m^2 (1.2 to 19.2 tons/acre)		
X(4)	Fuel weight, 1 to 10 cm	1.033 to 4.770 kg/m^2 (4.6 to 21.3 tons/acre)	25.00	99.9
X(7)	NFDRS BUI	1.5 to 237	18.20	99.9
X(11)	1/upper duff moisture content	0.0101 to 0.1333	4.49	99.9

Standard error of regression = 2.113

"F" = 36.23 (with 3 and 61 degrees of freedom)

$F_{(3, 61, \alpha = 0.01)} < F_{(3, 60, \alpha = 0.01)} = 4.13$

Additional variables tested:

X(1) = needle moisture content

X(6) = lower duff moisture content

X(10) = 1/needle moisture content

X(23) = surface area of needles

X(28) = 0 to 1 cm weight (g/m^2)

X(29) = 10+ cm fuel weight (g/m^2)

X(30) = fine fuel moisture

X(31) = 1/Buildup Index

The magnitude of bias became apparent when the equation of best fit provided data that were obviously incorrect. The fact that the coefficient for Buildup Index, X(7), is negative and highly significant implies that the higher the Buildup Index (or the drier the fuels) the smaller will be the amount consumed by fire. (Actually the drier the fuels the more consumed.) Several unsuccessful attempts were made to normalize this bias; consequently, we were not able to predict the amount of fuel loss based on preburn fuel or duff weight, moisture content, and weather.

In lieu of a mathematical relationship describing fuel losses, a set of case histories is offered (table 8). Fuel loadings and fuel losses are listed along with the BUI and the moisture content of the 0 to 1 cm fuels at the time of the fires. These data, although not suitable for statistical analyses, are accurate and represent a large number of carefully documented fires. This table may prove useful to those who contemplate burning similar fuels under similar moisture conditions. Each fire should [illegible] comparing individual fires.

Fire Characterization

[illegible] the ranking of *relative* intensity. Several techniques for estimating fire intensity [illegible]

Heat pulse to the site was measured with Beaufait's (1966a) water-can analog, a [illegible] placed (George 1969).

Standardized placement, recovery, and measurement of water-can analogs permits objective comparison among fires of varying severity, and a common vocabulary among land managers and fire researchers.

Table 8.--

Unit	Size class						Fuel loss	BUI	Fuel moisture	Unit	Size class						Fuel loss	BUI	Fuel moisture
	Preburn fuels						0-10 +				Preburn fuels						0-10 +		
	Needles	0-1	1-10	Subtotal	10 +	Total	needles		10-1 cm		Needles	0-1	1-10	Subtotal	10 +	Total	needles		10-1 cm
	MILLER CREEK										NEWMAN RIDGE								
N4	0.311	0.257	2.163	2.731	20.460	23.191	2.090	55	14	N1-1	0.196	0.171	2.379	2.747	22.729	25.166	3.268	42	10
N5	.302	.246	1.876	2.423	22.928	25.351	1.981	70	16	N1-2	.309	.314	1.747	2.370	17.417	19.987	2.364	42	10
N6	.241	.187	2.745	3.171	26.106	29.277	2.493	29	16	N1-3	.498	.360	1.641	2.437	34.204	36.641	2.350	42	10
N7	.401	.336	2.339	3.076	28.513	31.589	2.576	15	12	N2-1	.257	.157	1.866	2.260	22.860	25.120	1.944	88	13
N8	.389	.302	3.540	4.231	30.737	34.968	3.557	29	16	N2-2	.359	.256	2.195	2.808	29.195	32.003	2.378	88	13
N9	.294	.225	1.216	1.735	23.402	25.135	1.488	70	10	N2-3	.476	.270	1.742	2.488	18.648	21.136	2.245	88	13
N11	.596	.482	2.825	3.905	29.545	33.446	2.962	145	8	N3-1	.203	.226	2.445	2.874	17.625	20.497	--	--	--
N12	.442	.336	2.258	3.036	32.412	35.448	2.197	145	8	N3-2	.149	.174	1.750	2.073	16.473	18.525	--	--	--
N13	.372	.312	1.682	1.766	17.664	19.430	1.418	49	14	N3-3	.169	.179	1.960	2.308	12.349	14.657	--	--	--
N14	.376	.294	2.568	3.038	22.328	25.366	2.384	24	27	N4-1	.555	.298	2.160	2.795	25.476	28.269	--	--	--
N15	.362	.305	1.533	2.200	11.876	14.076	1.551	24	26	N4-2	.299	.265	1.685	2.249	21.624	23.873	--	--	--
										N4-3	.307	.251	1.492	2.053	16.556	18.589	--	--	-
E1	.318	.248	1.965	2.529	29.352	31.881	1.621	72	55										
E3	.537	.300	1.842	2.479	19.703	22.182	2.278	114	21	E1-1	.126	.140	3.142	3.408	20.724	24.132	3.178	38	12
E4	.475	.378	2.353	3.186	17.339	20.525	2.705	72	17	E1-2	.118	.109	2.755	3.062	15.597	18.599	2.781	38	12
E5	.355	.288	2.887	3.530	22.558	26.088	3.040	39	12	E1-3	.221	.191	2.432	2.844	22.386	25.230	2.680	38	12
E6	.395	.326	1.727	2.448	23.093	25.541	1.080	87	15	E2-1	.109	.123	1.579	1.811	25.556	27.367	--	--	--
E7	.474	.410	3.641	4.525	24.082	28.607	3.400	88	17	E2-2	.258	.198	1.646	2.102	15.267	17.369	--	--	--
E10	.354	.293	1.940	2.587	22.100	24.687	1.979	26	15	E2-3	.468	.304	1.740	2.512	19.417	21.929	--	--	--
E13	.245	.249	2.427	2.921	16.777	19.698	1.549	237	7	E3-1	.236	.199	1.479	1.914	13.938	15.852	1.502	90	13
E14	.362	.300	2.061	2.725	16.526	19.249	1.877	26	15	E3-2	.285	.256	2.116	2.657	20.456	23.113	2.199	90	13
										E3-3	.189	.146	1.487	1.822	20.613	22.435	1.407	90	13
S1	.325	.292	2.517	3.134	17.480	20.614	2.558	25	11										
S4	.300	.233	3.207	3.740	19.707	23.447	3.314	30	9	S1-1	.649	.347	4.770	5.766	16.307	22.073	5.506	29	5
S5	.324	.302	1.372	1.998	26.199	28.197	1.350	18	20	S1-2	.705	.412	4.467	5.584	16.802	22.382	5.447	29	5
S7	.231	.203	1.791	2.225	33.655	35.880	1.507	237	7	S1-3	.525	.409	4.658	5.592	14.874	20.466	5.558	29	5
S8	.192	.212	2.680	3.084	28.691	31.775	2.288	164	19	S2-1	.264	.247	2.606	3.117	25.154	28.271	2.708	56	8
S9	.346	.270	2.295	2.911	16.183	19.094	2.470	62	16	S2-2	.247	2.640	2.668	3.179	15.895	19.072	2.796	56	8
S10	.411	.322	2.215	2.948	26.881	29.829	2.518	30	9	S2-3	.250	.252	2.477	2.979	23.045	26.024	2.540	56	8
										S3-1	.373	.370	2.889	3.632	22.653	26.285	--	--	--
W1	.591	.509	3.761	4.861	27.561	32.422	4.065	111	13	S3-2	.449	.312	2.571	3.322	14.937	18.269	--	--	--
W2	.355	.296	1.856	2.507	25.216	27.723	1.837	237	7	S3-3	.351	.287	2.850	3.488	17.791	21.279	--	--	--
W3	.254	.208	1.777	2.239	19.931	22.170	1.773	18	20	S4-1	.401	.307	1.606	2.314	16.156	18.470	--	--	--
W4	.295	.296	1.587	2.178	17.876	20.054	1.649	18	18	S4-2	.273	.216	1.719	2.208	18.950	21.158	--	--	--
W5	.222	.218	2.525	2.965	19.649	22.614	1.868	237	7	S4-3	.308	.234	1.681	2.223	21.210	23.433	--	--	--
W7	.295	.230	1.699	2.224	23.571	25.795	1.122	237	7										
W8	.480	.400	1.033	1.913	28.625	30.538	1.692	64	15	W1-1	.462	.406	4.724	5.592	20.821	26.413	4.985	43	11
W9	.357	.271	1.556	2.184	16.182	18.366	1.852	64	17	W1-2	.700	.411	3.856	4.970	14.048	19.018	4.496	43	11
W10	.244	.192	2.479	2.915	16.984	19.899	2.708	68	8	W1-3	.406	.276	3.956	4.638	26.260	30.898	5.927	43	11
W11	.377	.309	2.066	2.752	27.117	29.869	2.451	23	10	W2-1	.216	.190	1.950	2.356	22.284	24.640	2.129	63	9
W12	.305	.262	2.107	2.674	22.925	25.599	2.013	32	17	W2-2	.263	.242	2.073	2.578	26.970	29.548	2.319	63	9
W13	.294	.290	1.195	1.779	17.174	18.953	1.231	32	17	W2-3	.265	.190	1.991	2.446	21.841	24.287	2.300	63	9
W14	.291	.256	2.147	2.694	22.261	24.955	2.133	32	17	W3-1	.168	.167	1.926	2.261	19.408	21.669	--	--	--
W15	.278	.229	1.120	1.627	32.415	34.042	1.189	22	17	W3-2	.248	.244	2.000	2.492	25.900	28.392	--	--	--
										W3-3	.187	.209	3.136	3.532	21.752	25.284	--	--	--
										W4-1	.275	.249	2.573	3.147	19.825	22.972	--	--	--
										W4-2	.281	.320	2.523	3.124	21.713	24.837	--	--	--
										W4-3	.277	.278	2.191	2.746	22.337	25.083	--	--	--

Thirty six water cans were installed on a 1 chain grid over each [illegible] sample plot. Cans were placed through the duff directly on the mineral soil surface (fig. 12) and holes were punched in the lids before burning. Immediately after the fires cooled the cans were weighed to determine how much of the original 3 kg of water had been evaporated (fig. 13).

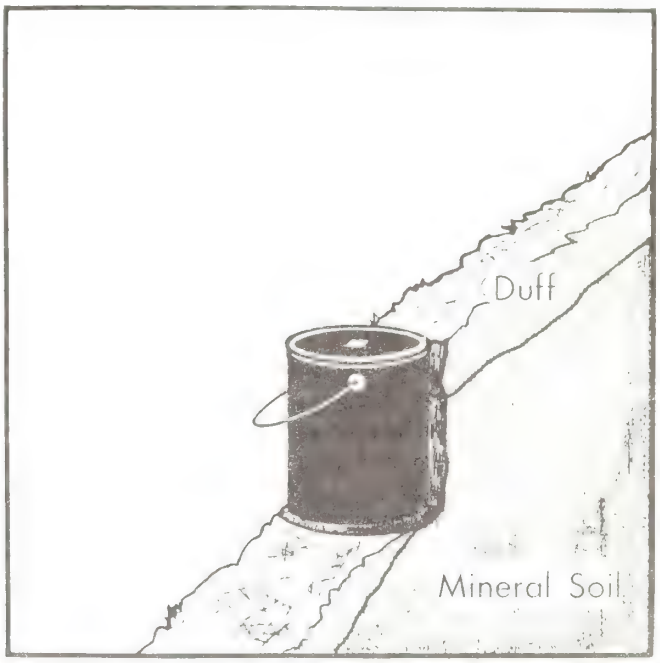


Figure 12.--Placement [illegible] water.

Figure 13.--[illegible]

Two expressions of fuel moisture are included as independent variables in the equation of best fit describing water can weight loss:

$$Y(1) = f\left(X(2), X(12)\right)$$

$$Y(1) = 536.45 - 5.53X(2) + 84.31X(12)$$

where:

Variables	*Description*	*Range*	*"t"*	*Level of significance (percent)*
Y(1)	Weight loss from water-can analogs	52.5 to 1,926.1 grams		
X(2)	Moisture content of upper duff	7.5 to 99+ percent	6.26	99.9
X(12)	Buildup Index	BUI 15 to 237	9.06	99.9

Standard error of regression = 211.38 grams

$F_{(2,\ 62\ \alpha\ =\ 0.01)} < F_{(2,\ 60\ \alpha\ =\ 0.01)} = 4.98$

Best equations were:

	R^2
$Y(1) = f\left(X(1), X(2), X(3), X(6), X(12)\right)$	0.77
$Y(1) = f\left(X(1), X(2), X(12)\right)$	.76
$Y(1) = f\left(X(2), X(12)\right)$	.74

Additional variables tested:

X(1) = needle moisture content

X(3) = slash depth

X(4) = 1 to 10 cm fuel weight

X(5) = adjusted fine fuel moisture

X(6) = lower duff moisture

X(7) = Buildup Index

X(9) = 1/fine fuel moisture (0 to 1 cm)

X(10) = 1/needle moisture

X(11) = 1/average upper duff moisture content

X(14) = 1/X(5)

Table 9.

Buildup index	Upper duff moisture content (percent)[1/]									
	10	20	30	40	50	60	70	80	90	100
25	700	650	590	540	480	430	[illegible]	[illegible]	260	[illegible]
50	880	820	770	710	660	[illegible]	550	[illegible]	[illegible]	380
75	1,010	960	900	850	790	730	680	[illegible]	[illegible]	510
100	1,120	1,070	1,010	960	900	[illegible]	790	[illegible]	680	[illegible]
125	1,220	1,170	1,110	1,060	1,000	950	[illegible]	840	[illegible]	[illegible]
150	1,310	1,260	1,200	1,150	1,090	1,040	[illegible]	930	[illegible]	[illegible]
175	1,400	1,340	1,290	1,230	1,180	1,130	1,060	1,010	[illegible]	900
200	1,470	1,420	1,360	1,310	1,250	1,200	1,140	1,090	1,030	[illegible]
225	1,550	1,490	1,440	1,380	1,320	1,270	1,210	1,160	[illegible]	1,050

[1/] Approximate range of collected data is indicated by internal line.

A table of solutions for the equation over the range of its applicability [illegible] in table 9. Values near 1,000 grams characterize "hot" fires; lower values represent "cool" fires. Heat pulse to the site can be computed from the same input data as used to estimate duff reduction--upper duff moisture content and Buildup Index. In fact, our analysis showed a strong, positive correlation between water-can weight loss and duff consumption. As a result of this correlation, an intensive review of study data was undertaken and an effort made to develop a relationship between heat released per unit of area by burning of the slash fuels and the reduction in depth of duff observed on the site (Albini 1975). The effort failed.

Infrared radiometer

An infrared radiometer, a device for measuring infrared radiation from a fixed area, was employed in this study. Typically, the radiometer was positioned on a hillside opposite the burn and focused on the center of the fire. The instrument read the average fire intensity over a 100 to 200 square meter area.

Ten fires were sufficiently documented to relate the radiometer data to water loss and duff reduction data. The data were analyzed to test if water-can weight loss and duff reduction, or both, are statistically related to radiometric infrared measurements.

Table 10 provides the basis for a regression analysis between radiometric data and water-can weight loss or duff depth reduction, where:

Y(1) = time-temperature areas (°F - min)

Y(2) = time-voltage areas (volt - min)

X(1) = water-can weight loss (g)

X(2) = duff depth reduction (cm)

A regression program was run for each pair of functions. The resulting equations, along with the associated F and R^2 values are listed in table 11. Many more observations and further analysis will be required before definitive correlations can be attempted.

[4] Norum, Rodney A. Infrared radiation as a measure of relative fire intensity. Unpublished report on file at the Northern Forest Fire Laboratory, USDA Forest Service. Missoula, Montana.

Table 10.--*Relationship of radiometric data to duff loss and water loss data*

Unit	Time-temperature	Time-volts	Duff loss	Water loss
			Cm	*G*
N4	15163350E+07	0.54450000E+04	1.28	496.81
N6	0312500E+07	.30450000E+04	1.15	302.91
N8	11709750E+07	.20700000E+04	.37	266.33
N14	14958150E+07	.29985000E+04	1.00	125.89
N15	6247100E+07	.54225000E+04	.73	136.97
E10	3525800E+07	.70725000E+04	.67	415.14
W5	13762800E+07	.53625000E+04	.57	423.03
W4	20335500E+06	.43500000E+03	.01	52.53
W12	3442300E+07	.97650000E+04	1.02	555.83
W15	23245950E+07	.87600000E+04	.83	288.44

Table 11.--*Regression equation relating radiometer data to duff loss and water loss data*

Y	X	Regression equation	F	R^2
Time-temperature	Water loss	Y = 1,955.8 + 884,782X	3.13	0.28
Time-temperature	Duff loss	Y = 683,070 + 1,196,058X	1.14	.13
Time-volts	Water loss	Y = 12.11 + 1,327.7X	7.03	.47
Time-volts	Duff loss	Y = 3,648.8 + 2,253.6X	2.28	.22

Rate-of-Spread Measurements

Rate-of-spread is an essential parameter in Byram's equation (Davis 1959) for estimating fire intensity. Fire spread measurements were attempted by using thermocouple networks on 2-1/2-acre units (fig. 14) and an infrared line scanner. Although both attempts failed, results are reported to guide future researchers.

A multipen recorder registered the time fire reached each thermocouple. It also recorded, in millivolts, the temperature equivalent of the wires as that particular circuit was sequenced. Construction and installation of thermocouple networks was difficult and time consuming. After initial use, reliability of the thermocouples was poor, consequently their use was abandoned after a few fires.

An infrared line scanner equipped with an uncooled lead selenide detector was also tested for collecting rate-of-spread data. The system picks up infrared emissions through smoke and darkness. Photographic records of its cathode ray display tube and magnetic tape data storage permit reconstruction of the fire front. Data reduction was too laborious and costly for completion. For example, distortion resulting from an oblique viewing point must be adjusted mathematically or graphically after viewing geometry is measured. The data collected, when properly reduced, might prove useful in fire modeling, especially for model verification.

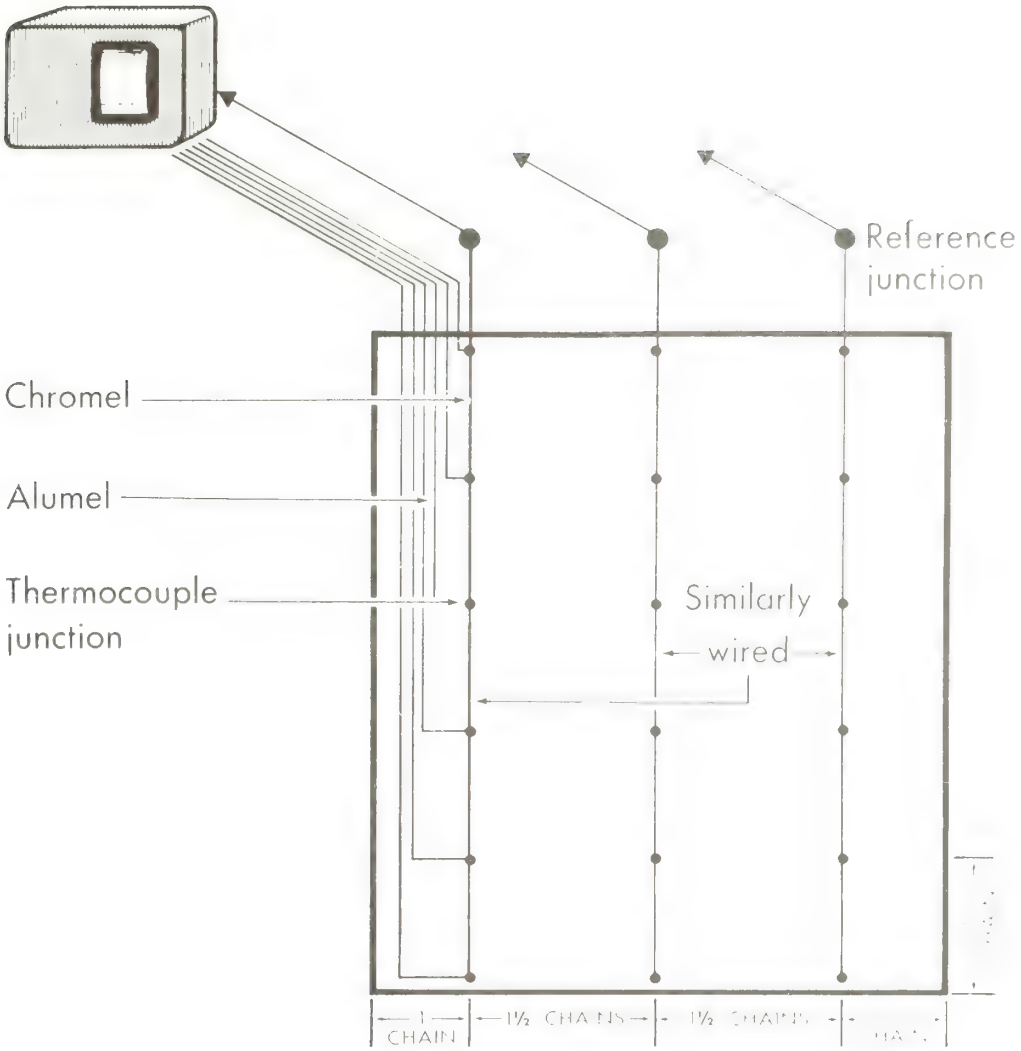


Figure 14.--Thermocouple network to measure pattern of [illegible]

SUMMARY

This report provides a project record for the Miller Creek-Newman Ridge Study. The overall objective of this study was to develop criteria for scheduling prescribed fires to accomplish site preparation and hazard reduction needs. Results apply to broadcast burning of western larch/Douglas-fir clearcuts in western Montana.

The fuel complex resulting from clearcutting in larch/fir stands is characterized in this report. Fuel distribution and loading by size class is described for the four cardinal exposures. Range and frequency of occurrence of fuel moisture conditions is documented for a 3-year period and should be of value to managers writing hazard reduction plans and fire prescriptions for larch/fir clearcuts.

An equation is presented for predicting duff depth reduction from upper duff moisture content and Buildup Index. This equation, or the table of solutions, can assist managers in determining burning conditions required for adequate site preparation in conjunction with natural regeneration schemes.

Fuel reduction can be estimated from the 62 case studies of fuel loss presented herein. This information can be helpful in identifying burning conditions necessary to accomplish fuel management objectives.

Fifty-five fires were successfully ranked according to fire intensity. Consequently, the results of ancillary studies will be related to fire intensity, which will provide the forest manager with an increased capability to evaluate the environmental impact of planned prescribed fires in larch/fir stands.

Although the research findings reported here do not provide the often sought "magic formula" for prescribed burning, a manager can greatly increase the probability of a successful burn by considering these results when writing fire prescriptions.

PUBLICATIONS CITED

Adams, D. F., and R. K. Koppe.
1969. Instrumenting light aircraft for air pollution research. J. Air Pollution Control Assoc. (APCA J.), 19(6):410-415.

Albini, Frank A.
1975. An attempt (and failure) to correlate duff removal and slash fire heat. USDA For. Serv., Gen. Tech. Rep. INT-24, 16 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Beaufait, William R.
1960a. Influence of shade level and site treatment, including fire, on germination and early survival of *Pinus banksiana*. Mich. Dep. Conserv., For. Div., p. 79.

Beaufait, William R.
1960b. Some effects of high temperatures on the cones and seeds of jack pine. For. Sci. 6:194-199.

Beaufait, William R.
1962. Procedures in prescribed burning for jack pine regeneration. Mich. Coll. Mining and Tech., Tech. Bull. 9, p. 39.

Beaufait, William R.
1966a. An integrating device for evaluating prescribed fire. For. Sci. 12:27-29.

Beaufait, William R.
1966b. Prescribed fire planning in the Intermountain West. USDA For. Serv. Res. Pap. INT-26, p. 27. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Beaufait, William R., and William C. Fischer.
1969. Identifying weather suitable for prescribed burning. USDA For. Serv. Res. Note INT-94, p. 7. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Beaufait, William R., Michael A. Marsden, and Rodney A. Norum.
1974. Inventory of slash fuels using 3P subsampling. USDA For. Serv. Gen. Tech. Rep. INT-13, p. 17, Intermt. For. and Range Exp. Stn., Ogden, Utah.

Boe, K. N.
1952. Effects of slash disposal on lodgepole pine regeneration. Proc. Mont. Acad. Sci. 12:27-33.

Brown, James K.
1970. Vertical distribution of fuel in spruce-fir logging slash. USDA For. Serv. Res. Pap. INT-81, 9 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Brown, James K.
1974. Handbook for inventorying downed woody material. USDA For. Serv. Gen. Tech. Rep. INT-16, p. 24, Intermt. For. and Range Exp. Stn., Ogden, Utah.

Buckman, R. E.
1962. Two prescribed summer fires reduce abundance and vigor of hazel brush regrowth. U.S. Dep. Agric., Lake States For. Exp. Stn. Tech. Note 620, p. 2.

Buckman, R. E.
1964. Effects of prescribed burning on hazel in Minnesota. Ecology 45(3):626-629.

Byram, George M.
1959. Combustion of forest fuels, and forest fire behavior. *In* Forest fire: control and use. Chap. 3 and 4. New York: McGraw-Hill Book Co.

Chapman, H. H.
1926. Factors determining natural reproduction of longleaf pine on cut-over lands in LaSalle Parish, Louisiana. Yale Univ. Sch. For. Bull. 16, p. 44.
Chapman, H. H.
1942. Management of loblolly pine in the pine-hardwoods region in Arkansas and in Louisiana west of the Mississippi River. Yale Univ. Sch. For. Bull. 49, p. 150.
Chrosciewicz, Z.
1959. Controlled burning experiments on jack pine sites. For. Branch Can. Tech. Note-72, p. 19.
Daubenmire, R.
1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecol. Monogr. 22:301-330.
Davis, K. P.
1959. Forest fire: control and use. New York: McGraw-Hill Book Co. 584 p.
Davis, K. P., and K. A. Klehm.
1939. Controlled burning in the western white pine type. J. For. 37:399-407.
DeByle, Norbert V.
1973. Broadcast burning of logging residues and the water repellency of soils. Northwest Sci. 47(2):77-87.
DeByle, Norbert V., and Paul E. Packer.
1972. Plant nutrient and soil losses in overland flow from burned forest clearcuts. *In* Proc. Natl Symp. on Watersheds in Transition, p. 296-307.
Fahnestock, George R.
1960. Logging slash flammability. USDA For. Serv. Res. Pap. INT-58, p. 67. Intermt. For. and Range Exp. Stn., Ogden, Utah.
Fahnestock, George R., and John H. Dieterich.
1962. Logging slash flammability after 5 years. USDA For. Serv. Res. Pap. INT-70, p. 15. Intermt. For. and Range Exp. Stn. Ogden, Utah.
Ferguson, E. R., and G. K. Stephenson.
1954. Fire effects studies in east Texas. USDA For. Serv., Fire Control Notes 15(3):30-32.
Fischer, William C.
1969. 1967 Fire danger in the northern Rocky Mountains. USDA For. Serv., p. 25. Intermt. For. and Range Exp. Stn., Ogden, Utah.
Fischer, William C., William R. Beaufait, and Rodney A. Norum.
1969. The hygrothermoaerograph--construction and fire management application. USDA For. Serv., Res. Note INT-87, p. 8. Intermt. For. and Range Exp. Stn., Ogden, Utah.
Fischer, William C., and Charles E. Hardy.
1972. Fire-weather observers' handbook. 152 p. USDA For. Serv., Intermt. For. and Range Exp. Stn., Ogden, Utah.
Flaherty, David C.
1967. Better burns. . . and better air? Quest Magazine, 5(4):16-21, Wash. State Univ., Pullman.
Fosberg, Michael A.
1970. Drying rates of heartwood below fiber saturation. For. Sci. 16:57-63.
George, Charles W.
1969. A water-can analog--its thermal characteristics and calibration. M.S. thesis, Sch. For., Univ. Mont., Missoula.
Grosenbaugh, L. R.
1967. REX--Fortran-4 system for combinatorial screening or conventional analysis of multivariate regressions. USDA For. Serv. Res. Pap. PSW-44, p. 47. Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.
Hanson, H. C.
1929. Improvement of sagebrush range in Colorado. Colo. Agric. Exp. Stn. Bull. 365, p. 12.

LeBarron, R. K.
1957. Silvicultural possibilities of fire in northeastern Wisconsin. J. For. 55:627-630.
Lindenmuth, A. W.
1960. A survey of effects of intentional burning on fuels and timber stands of ponderosa pine in Arizona. USDA For. Serv. Res. Pap. RM-54, p. 22. Rocky Mt. For. and Range Exp. Stn. Fort Collins, Colo.
Little, S.
1953. Prescribed burning as a tool of forest management in the northeastern states. J. For. 51:496-500.
Little, S., and H. A. Somes.
1949. Slash disposal in oak-pine stands of southern New Jersey. USDA For. Serv. Res. Pap. NE-31, p. 12. Northeastern For. and Range Exp. Stn, Upper Darby, Pa.
Lotti, Thomas.
1956. Growing loblolly pine in the south Atlantic States. U.S. Dep. Agric. Farmers' Bull. 2097, p. 33.
Lyman, C. E.
1945. Principles of fuel reduction for the northern Rocky Mountain Region. USDA For. Serv., Northern Rocky Mt. For. and Range Exp. Stn. Progr. Rep. 1, p. 98. Missoula, Mont.
McGilvrey, R. C.
1950. Management of natural slash pine stands in the flatwoods of south Georgia and north Florida. U.S. Dep. Agric., Circ. 845, p. 57.
Morris, W. G.
1966. Guidelines offered for slash burning. For. Ind. 93(10):62-63.
Morris, W. G.
1970. Effects of slash burning in overmature stands of the Douglas-fir region. For. Sci. 16:258-270.
Morris, W. G., and E. L. Mowat.
1958. Some effects of thinning a ponderosa pine thicket with a prescribed fire. J. For. 56:203-209.
Norum, Rodney A.
1970. Probable smoke column heights from slash fires. M.S. Thesis, Univ. Mont., Missoula. 65 p.
Norum, Rodney A.
1974. Smoke column height related to fire intensity. USDA For. Serv., Res. Pap. INT-157, p. 7. Intermt. For. and Range Exp. Stn., Ogden, Utah.
Olson, D. S., and G. R. Fahnestock.
1955. Logging slash--a study of the problem in Inland Empire forests. Univ. Idaho For. Wild. and Range Exp. Stn. Bull. 1, p. 48.
Packer, Paul E.
1971. Site preparation in relation to environmental quality. *In* Maintaining productivity of forest soils. P. 23-28. 1971 West. For. and Conserv. Assoc., Portland, Oreg.
Pearson, G. A.
1950. Management of ponderosa pine in the Southwest. U.S. Dep. Agric., Agric. Mont. 6, p. 218.
Pechanec, J. F., G. Stewart, and J. P. Blaisdell.
1954. Sagebrush burning--good and bad. U.S. Dep. Agric., Farmers' Bull., 1948, p. 32.
Roe, Arthur L., William R. Beaufait, L. Jack Lyon, and Jerry L. Oltman.
1971. Fire and forestry in the northern Rocky Mountains--a task report. J. For. 68(8):464-470.
Rothermel, Richard C., and Hal E. Anderson.
1966. Fire spread characteristics determined in the laboratory. USDA For. Serv. Res. Pap. INT-30, p. 34. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Shantz, H. L.
1947. The use of fire as a tool in the management of brush ranges in California. Calif. State Board For., p. 156.
Siggers, P. V.
1934. Observations on the influence of fire on the brown spot needle blight on longleaf pine seedlings. J. For. 32:556-562.
Smith, N. F.
1947. Controlled burning in Michigan's forest and game management programs. Soc. Am. For. Proc. 1947:200-205.
Society of American Foresters.
1958. Forest terminology. Ed. 3, p. 97. Soc. Am. For., Washington, D.C.
Society of American Foresters.
1967. Forest cover types of North America. P. 67. Soc. Am. For., Washington, D. C.
Steele, Robert W.
1964. Effects of prescribed burning on forest duff depth. West. For. and Conserv. Assoc. Annu. Meet. Proc. 1964:20-21.
Steele, Robert W., and William R. Beaufait.
1969. Spring and autumn broadcast burning of interior Douglas-fir slash. Mont. For. and Conserv. Exp. Stn. Bull. 36, p. 12.
Thomas, P. H.
1958. On the rate of burning of cribs of wood. Joint Fire Res. Organ. Boreham Wood, Herts, England. Fire Res. Note 370.
Thomas, P. H.
1963. The size of flames from natural fires. *In* Ninth Int. Symp. Combust., p. 844-859. New York: Acad. Press.
U.S. Department of Agriculture, Forest Service.
1964. National fire-danger rating handbook. USDA For. Serv. Handb. 5109.11.
U.S. Department of Agriculture, Forest Service.
1965. Compartment prescription handbook. USDA For. Serv. Handb. 2411.14, Reg. 1. (Recently recatalogued 2409.21d.)
Van Wagner, C. E.
1965. Prescribed burning experiments red and white pine. Can. Dep. For. Publ. 1020, p. 27.
Wikstrom, J. H., and J. R. Alley.
1967. Cost control in timber growing on the national forests of the Northern Region. USDA For. Serv. Res. Pap. INT-42, p. 37. Intermt. For. and Range Exp. Stn., Ogden, Utah.
Weaver, Harold.
1955. Fire as an enemy, friend, and tool in forest management. J. For. 53:499-504.
Wellner, C. A.
1946. Recent trends in silvicultural practice on national forests in the western white pine type. J. For. 44:942-944.
Williams, D. E.
1958. Two control-burns in jack pine cut-over. For. Branch Pulp and Pap. Mag. Can., p. 5.

APPENDIX A: PUBLICATIONS— MILLER CREEK-NEWMAN RIDGE STUDY

Part I: Published Papers

Adams, Donald F., and Robert K. Koppe.
1969. The use of real time airborne instrumentation. Paper 69-AP-27. 12 p. Wash. State Univ., Pullman.

Airborne instrumentation was used to study smoke plumes from experimental prescribed burns conducted by the Northern Forest Fire Laboratory and Region 1 foresters. Burns were scheduled between May and November each summer to represent a variety of fuel moisture and meteorological conditions.

Flights were made through the smoke plumes with real time instrumentation to establish aerosol concentrations and size distribution, visual range, and carbon dioxide profiles. Flight patterns were selected to characterize plume transport and dispersion downwind under known meteorological conditions. Data demonstrate the utility of airborne real time instrumentation in air pollution research.

Adams, D. F., and R. K. Koppe.
1969. Instrumenting light aircraft for air pollution research. J. Air. Pollut. Control Assoc. 19(6):410-415.

The airborne instrumentation package described measures and records up to 27 pollutant and flight variables. Real-time analysis instrumentation include nondispersive infrared analyzers for CO_2, CO, and hydrocarbons, conductivity and coulometric analyzers for sulfur dioxide and sulfur-containing gases, and Charlson-Ahlquist visual range nephelometer. A Battelle "bulk sampler" is used to collect particulates. Air speed, altitude, rate of climb, magnetic heading, temperature, and relative humidity are continuously measured. All variables are recorded on magnetic tape. Tape data are reduced directly by IBM 360 computer to a digital printout or from tape to an X-Y analog plot.

Beaufait, William R.
1968. Scheduling prescribed fires to alter smoke production and dispersion. *In* Prescribed Burning and Management of Air Quality, Southwest Interagency Fire Counc. Proc. 1968:33-42.

The Northern Region-Intermountain Station cooperative study of the use of fire in silviculture is described. The author discusses data collection instrumentation, especially that associated with Washington State University's air pollution research group's activities. Some preliminary results indicate that convection columns rose to a higher altitude and smoke plumes were more greatly dispersed from Miller Creek burns when fuels were relatively dry and lapse rate was favorable than under the reverse conditions. To minimize smoke effects, fires should be scheduled when fuels are dry enough to create a strong convection column. Meteorological and fuel conditions required for adequate smoke dispersion can be made to correspond with those that achieve the beneficial goals of prescribing burning.

Beaufait, William R.
1971. Fire and smoke in Montana forests. *In* Land use and the Environment. Mont. For. and Range Exp. Stn. Sch. For. Univ. Mont., Missoula.

Beaufait, William R., and Owen P. Cramer.
1969. Prescribed fire smoke dispersion-principles. USDA For. Serv., In-Serv. Rep., 12 p. Missoula, Mont. (Rev. Jan. 1972)

An illustrated presentation of the principles that must be considered in developing prescribed burning guidelines and in successfully conducting prescribed fires that result in efficient smoke management.

Beaufait, William R., and William C. Fischer.
1969. Identifying weather suitable for prescribed burning. USDA For. Serv. Res. Note INT-94, 7 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Fire managers required 24-hour records of temperature, relative humidity, and windspeed to use fire efficiently and effectively. When carefully calibrated and interpreted, modified hygrothermographs provide minimum instrumentation to obtain these records. An actual case of record interpretation and use is included.

Beaufait, William R., Michael A. Marsden, and Rodney A. Norum.
1974. Inventory of slash fuels using 3P subsampling. USDA For. Serv. Gen. Tech. Rep. INT-13, 17 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

The Northern Region-Intermountain Station cooperative studies of the use of fire in silviculture required the development of a system to inventory clearcut logging slash fuels, both before and after treatment, by broadcast fires of varying intensity. This paper describes the theory, sampling design, field procedures, and data processing programs for the inventory systems that were developed and applied on 100 2-1/2-acre plots. The method employed is a variation on the line transect technique which utilizes line intersect counts to compute fuel volume, weight, and surface area. The method and results should be of value to those who wish to quantify similar slash fuels.

Brown, James K.
1970. Vertical distribution of fuel in spruce-fir logging slash. USDA For. Serv. Res Pap. INT-81, 9 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

About 70 percent of the volume and surface area of spruce-fir logging slash lies below the mid-depth of the slash. Material 0 to 1 centimeter in diameter was distributed vertically in the same proportions as all other material. Old slash in the first

20 centimeters above the ground contained a higher proportion of large material than new slash. Quantity of slash averaged 26.5 kg/m (118 tons/acre) dry weight with 0.57 kg/m composed of material 0 to 1 centimeter in diameter. Bulk density of slash decreased vertically and averaged 0.030 g/cc for new slash and 0.053 for old slash. Needle mats suspended in the slash occurred with a 40 percent frequency.

DeByle, Norbert V.
1973. Broadcast burning of logging residues and the water repellency of soils. Northwest Sci. 47:77-87.

Pertinent literature is reviewed and summarized. Water repellency of both organic and mineral soil horizons under larch and Douglas-fir were evaluated. Effects of prescribed broadcast burning on soil wettability are described.

DeByle, Norbert V., and Paul E. Packer
1972. Plant nutrient and soil losses in overland flow from burned forest clearcuts. Watersheds in Transition AWRA Symp. Proc., 296-307.

Describes the results of analyses of the overland flow and sediment from 24 runoff plots. Logging and burning temporarily impaired watershed protection and increased overland flow and erosion. However, vegetal recovery returned conditions to near prelogging status within four years. There was an increase in plant nutrient losses in both the sediment and in the overland flow during the denuded period; but it represented only a small fraction of the nutrient capital on these sites.

Fischer, William C., William R. Beaufait, and Rodney A. Norum.
1969. The hygrothermoaerograph--construction and fire management application. USDA For. Serv. Res. Note INT-87, 8 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Conventional hygrothermographs can be modified to record windspeed along with temperature and relative humidity. The fire-weather record resulting from the modification has application in prescribed fire planning, fire-danger rating, fire-weather forecasting, fire behavior analysis, and fire-weather climatology.

Flaherty, David C.
1967. Better burns. . . and better air? Quest, Dec. 1967, p. 16-21, Wash. State Univ., Pullman.

This article, written in popular style, summarizes the objectives of the Miller Creek study and highlights the air pollution research of Washington State University.

Flaherty, David C.
1972. Are we objective about forest fires? Am. For. 78(9):12-15, 58-59.

A popular article concerning fire's role in the environment based on an interview with Dr. W. R. Beaufait. Beaufait explains why fire is a natural component of the northern Rocky Mountain forests. He describes how the Northern Region-Intermountain Station cooperative studies are contributing to a better understanding of the use of fire in silviculture.

Hardy, Charles E., and others.
1969. The Newman Ridge study. USDA For. Serv., Northern Reg. and Intermt. For. and Range Exp. Stn. 6 p.

A brochure describing the objectives and purpose of the Northern Region-Intermountain Station cooperative studies of the use of fire in silviculture. Deals with the history of the study, work being conducted on the Newman Ridge block, study design, instrumentation, and data-collection methods.

Koppe, Robert K.
1968. Forest fire smoke study. Quest Annu. Rep. 1968:12-13, Wash. State Univ., Pullman.

Koppe, Robert K., and Donald F. Adams.
1969. Dispersion of prescribed fire smoke. Pap. 69-AP-36, 21 p. Wash. State Univ., Pullman.

Describes smoke plumes resulting from prescribed burning of forest slash in the Miller Creek drainage, Flathead National Forest, near Kalispell, Mont. Results of airborne sampling for aerosol detection and for carbon dioxide analysis of two typical prescribed burns are described. Rate of plume spread was calculated for one burn as the plume was carried downwind by the winds aloft. The major portion of the plume was transported at 3,950 m at a rate between 14.8 and 20.9 m/sec. The average winds aloft speed was calculated to be 11.2 m/sec.

Simultaneous aerosol and carbon dioxide measurements show excellent correlation between smoke particles and increased carbon dioxide concentration for approximately 25 km downwind from prescribed burn plots. The carbon dioxide level in the diffusing plume was approximately 10 percent above background. From 25 to 55 km downwind the carbon dioxide concentration in the plume and the background were comparable, although the boundary of the plume was clearly discerned by the sampling instruments. Aerial intercepts of the edge of the convection column during the initial buildup phase of the fire revealed carbon dioxide concentrations up to 500 ppm.

Malte, P. C.
1974. Smoke production from forest slash burning: 1969 Montana fires at Newman Ridge. Internal Rep., Wash. State Univ., Pullman.

The percentage of slash fuel converted to smoke is presented for three of the 1969 Newman Ridge fires. Concentrations of particular matter and CO_2 were determined from airborne sampling devices, fuel inventories and moisture content data in conjunction with elemental analyses for C/H/N atom ratios, and burning table results.

Norum, Rodney A.
1974. Probable smoke column heights from slash fires. M.S. Thesis, 65 p. Univ. of Mont., Missoula.

Norum, Rodney A.
1974. Smoke column height related to fire intensity. USDA For. Serv., Res. Pap. INT-157, 7 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

The utlimate height of slash-fire smoke columns is shown to be strongly related to the character of the fire and only loosely related to lapse rate and other measures of atmospheric stability.

O'Dell, Clyde A.
1970. Analysis of USFS meteorological and WSU aircraft air quality data from western Montana. Prog. Rep., 16 p., Wash. State Univ., Pullman.

Describes an effort by the University of Washington and Washington State University to develop a first-approximation, large-scale diffusion model of forest fire smoke from the air quality data and meteorological observations obtained during Northern Region-Intermountain Station prescribed fire study. Anticipated yield would be prediction of smoke concentration downwind under various fuel conditions and loadings, atmospheric stability, and wind. The report describes the data available and difficulties incurred in analysis. It also gives summarized results of data analyzed.

Packer, Paul E.
1972. Site preparation in relation to environmental quality. Proc. 1972 Annu Meet. of West. For. and Conserv. Assoc. p. [illegible]

Summarizes the current knowledge about objectives and methods of site preparation for forest regeneration in relation to environmental quality. Discusses disposition of logging residue, reduction or elimination of plant competition, preparation of mineral soil seedbeds, and provision of favorable microenvironment. Covers the effect of prescribed fire, chemical treatment, and various mechanical methods of site preparation in relation to air and water pollution. Reviews new and needed development in site preparation.

Packer, Paul E.
1972. Effects of prescribed slash burning on watershed behavior of larch/Douglas-fir forest. Proc. XV IUFRO Congr., Univ. Florida, Gainesville.

Experiments in the Flathead National Forest in Montana showed that jammer logging changed surface soil properties and vegetative characteristics to enhance hydrology and soil stability. Prescribed burning proved to be detrimental to watershed in terms of runoff and soil erosion, but the effect only appears to last a few years. The soil erosion behavior of logged-burned units seems related more to the amount of protective groundcover and the climate than to other site factors.

Robinson, E.
1973. Dispersion of slash-burn smoke over forest areas. Pap. 73-AP-44, Coll. of Eng., Wash. State Univ., Pullman.

Robinson, Elmer, Donald F. Adams, and Robert K. Koope.
[n.d.] Dispersion of slash fire smoke plumes. Internal Rep., Wash. State Univ., Pullman.

Part II: Papers in Preparation

DeByle, Norbert V.
[n.d.] Soil fertility as affected by prescribed broadcast burning following clearcutting in northern Rocky Mountain larch/fir forests. *In* Proc. Fire and Land Manage. Symp., Oct. 8-10, 1974; Missoula, Mont., Tall Timbers Fire Res. Stn., and Intermt. Fire Res. Counc.

Plant nutrients and associated parameters were determined for soils under more than 40 monitored experimental burns of broadcast logging debris in western Montana. The duff or ash-duff mixture, and the 0 to 5, 5 to 10, 10 to 20, and 20 to 30 cm depths into mineral soil were sampled before, immediately after, and for up to 2 years after burning. Data are reported for pH, cation exchange capacity, and organic matter, total nitrogen, available and total phosphorus, exchangeable soluble and total potassium, sodium, calcium, and magnesium. Relationships of soil parameters to clearcutting and intensity of fire are discussed. Reports conclusions about effects of these treatments on the availability and supply of plant nutrients in medium to fine-textured soils derived from Belt series rocks.

Fiedler, Carl.
[n.d.] Wind movement in and around clearcuts, and possible seed dissemination implications. M.S., Sch. of For. Univ. Mont., Missoula.

Wind movement over two clearcuts of opposing aspect and the intervening ridge was studied. Three recording weather stations were used to gather continuous data on windspeed and direction. Supplemental data were obtained from a series of weather balloons on 100 foot lines, placed along the clearcut edges. Movement of these balloons with changing wind patterns was recorded by means of time lapse photography. Dispersal of smoke from smoke grenades was also photographed to aid in defining wind variation within units. Comparisons are made between wind behavior on opposite aspects and the ridgetop, and possible effects on seed dissemination are discussed.

Halvorson, Curtis H.
[n.d.] Effects of prescribed broadcast burning on small mammal populations in northern Rocky Mountain larch/fir forests. *In* Proc. Fire and Land Manage. Symp. Oct. 8-10, 1974; Missoula, Mont. Tall Timbers Fire Res. Stn., and Intermt. Fire Res. Counc.

Packer, Paul E.
[n.d.] Surface runoff and soil erosion as affected by prescribed broadcast burning following clearcutting in northern Rocky Mountain larch/fir forests. *In* Proc. Fire and Land Manage. Symp., Oct. 8-10, 1974; Missoula, Mont. Tall Timbers Fire Res. Stn., and Intermt. Fire Res. Counc.

Shearer, Raymond C.
1975. Seedbed characteristics in western larch forests after prescribed burning. USDA For. Serv. Res. Pap. INT-167, 26 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Establishment of western larch seedlings is favored by site preparation that reduces the duff layer and sprouting of competing vegetation. A cooperative study of the use of fire in silviculture in northwestern Montana provided conditions to study the effectiveness of prescribed burning of logging slash for seedbed preparation from May through October. Greatest duff reduction, root mortality, and soil heating occurred when duff and soil water contents were lowest. Duff on north-facing slopes dries more slowly than on other aspects and the slash must be burned in the summer when the duff is dry to reduce the organic mantle and to prepare satisfactory seedbed. Summers of frequent rainfall may prevent satisfactory preparation of seedbeds on north slopes. East-, south-, and west-facing slopes have a wider range of time when burning will prepare seedbeds suitable for natural regeneration.

Shearer, Raymond C.
[n.d.] Establishment of conifers following prescribed broadcast burning in northern Rocky Mountain forests. *In* Proc. Fire and Land Manage. Symp., Oct. 8-10, 1974; Missoula, Mont., Tall Timbers Fire Res. Stn., and Intermt. Fire Res. Counc.

Regeneration of conifers following prescribed broadcast burning was studied on 40 clearcuts made in stands of western larch and associated species on north-, east-, south-, and west-facing slopes at two locations in western Montana. Natural regeneration success was more dependent on moisture gradients, as reflected by habitat types, than on the amount of mineral soil seedbed exposed by burning. The effect of prescribed burning on soil water, soil temperature, duff reduction, and mortality of nonconiferous roots is discussed. Seasonal fluctuations of seed crops, soil water, and soil temperature are related to seedling establishment.

APPENDIX B: DETAILED TREATMENT SCHEDULE

Unit	Data used in analysis: Logged	Slashed	Burned	Data held out: Unit	Logged	Slashed	Burned	Salvaged unit	Logged, unslashed		Wildfire	
N4	8/67	10/67	8/31/68					N1				
N5	1/67	3/67	10/9/67									
N6	8/67	10/67	[illegible]					[illegible]				
N7	1/67	2/67	6/18/68					N10				
N8	1/68	2/68	[illegible]									
N9	7/67	9/67	7/26/68									
N11	2/67	3/67	8/3/67									
N12	2/67	3/67	8/3/67									
N13	7/67	7/67	7/8/68									
N14	1/68	2/68	10/3/68									
N15	1/68	2/68	10/3/68									
S1	6/67	6/67	5/18/68					[illegible]	1/S14	10/66	8/67	1/S12	8/67
S2	12/67	[illegible]	5/18/68						1/S15	10/66	8/67		
S3	7/67	2/68	5/18/68										
S4	12/67	2/68	7/3/68										
S5	10/67	11/68	9/30/68										
S6	7/67	8/67	8/23/67										
S7	5/67	5/67	8/23/67										
S8	4/67	5/67	8/8/67										
S9	2/67	6/67	10/5/67										
S10	2/67	5/67	7/5/68										
E1	7/67	7/67	10/10/67	[illegible]	11/67	[illegible]	10/1/70	[illegible]				2/E12	8/67
E6	10/67	11/67	8/7/68	[illegible]	11/67	12/67	10/1/70						
E4	8/67	11/67	7/18/68										
E5	8/67	11/67	7/5/68										
E9	6/67	6/67	10/2/67										
E7	2/67	2/67	7/18/67										
E10	11/67	12/67	9/9/68										
E11	2/67	2/67	8/23/67										
E13	2/67	2/67	8/23/67										
E14	11/67	12/67	9/9/68										
E15	2/67	2/67	7/18/67										
W1	2/67	3/67	7/27/67									2/W6	8/67
W2	3/67	5/67	8/23/67										
W3	10/67	10/67	9/30/68										
W4	10/67	11/67	9/5/68										
W5	7/67	7/67	8/23/67										
W7	3/67	6/67	8/24/67										
W8	10/67	11/67	7/24/68										
W9	6/67	7/67	10/7/67										
W10	[illegible]	10/67	[illegible]										
W11	7/67	7/67	6/6/68										
W12	7/67	10/67	8/30/68										
W13	1/68	[illegible]	8/30/68										
W14	1/68	2/68	10/2/68										
W15	1/68	2/68	10/2/68										
N1	[illegible]	9/68	7/14/69	[illegible]	6/69	[illegible]	9/29/70	[illegible]					
N2	8/68	6/69	7/25/69										
S1	7/68	7/68	6/4/69	[illegible]	6/69	[illegible]	9/15/70	S1					
S2	9/68	11/68	7/16/69										
E1	7/68	8/68	7/9/69						E1	7/69	7/69		
E2	11/68	[illegible]	7/25/69										
E3	[illegible]	[illegible]	7/25/69										
W1	8/68	8/68	6/1/69	[illegible]	11/68	[illegible]	9/28/70						
W2	9/68	11/68	7/18/69	[illegible]	7/69	8/69	9/29/70						

1/ Subsequently machine piled and burned.

[illegible] Unsalvaged, special study unit.

3/ Burned 3 years after harvest, subject to special study.

4/ Burned 2 years after harvest, subject to special study.

APPENDIX C: PREBURN MOISTURE CONTENTS

Table 12.--*Average preburn moisture content of fuel components by block and unit*

Unit	Burn date	Duff		Litter	Slash		
		Lower 1/2	Upper 1/2		Needles	Branchwood 0-1 cm	Branchwood 1-10 cm
		Percent					
				MILLER CREEK			
N-4	8-31-68	99+	67	25	10	14	16
N-5	10-9-67	99+	85	48	6	15	37
N-6	9-10-68	99+	81	35	23	15	20
N-7	6-18-68	99+	45	10	18	12	37
N-8	9-10-68	99+	81	35	23	15	20
N-9	7-26-68	76	67	8	7	10	17
N-11	8-3-67	51	34	6	5	7	25
N-12	8-3-67	51	34	6	5	7	25
N-13	7-8-68	99+	95	13	7	13	17
N-14	10-3-68	99+	97	26	19	26	27
N-15	10-3-68	99+	97	26	19	26	27
E-1	10-10-67	90	99+	36	10	32	16
E-3	8-7-68	85	54	9	6	21	26
E-4	7-18-68	99+	77	15	12	17	38
E-5	7-5-68	99+	76	5	6	12	20
E-6	10-2-67	70	94	26	13	15	15
E-7	7-18-67	54	48	5	23	17	28
E-10	9-9-68	99+	55	23	13	15	17
E-13	8-23-67	56	24	5	4	6	18
E-14	9-9-68	99+	55	23	10	15	17
E-15	7-18-67	54	48	5	23	17	28
S-1	5-18-68	99+	28	6	8	11	21
S-2	5-18-68	99+	28	6	8	11	21
S-3	5-18-68	99+	28	6	8	11	21
S-4	7-3-68	99+	71	7	6	9	18
S-5	9-30-68	99+	65	20	18	20	35
S-7	8-23-67	56	24	5	4	6	18
S-8	8-8-67	28	43	7	24	19	22
S-9	10-5-67	77	99+	68	10	15	13
S-10	7-3-68	99+	71	7	6	9	18
W-1	7-27-67	94	47	4	16	12	19
W-2	8-23-67	56	24	5	4	6	18
W-3	9-30-68	99+	65	20	18	20	35
W-4	9-5-68	99+	99+	32	12	18	29
W-5	10-9-67	56	24	5	4	6	18
W-7	8-24-67	56	24	5	4	6	18
W-8	7-24-68	63	85	16	8	14	33
W-9	10-7-67	52	89	34	11	17	17
W-10	7-16-68	78	41	9	6	7	9
W-11	6-6-68	99+	99+	38	9	12	19
W-12	8-30-68	99+	84	50	18	17	22
W-13	8-30-68	99+	84	50	18	17	22
W-14	10-2-68	99+	97	27	15	17	24
W-15	10-2-68	99+	97	27	15	17	24
				NEWMAN RIDGE			
N-1	7-14-69	54	17	9	6	10	11
N-2	7-25-69	63	16	8	8	13	7
E-1	7-9-69	45	13	6	9	11	13
E-2	7-25-69	63	16	8	8	13	7
E-3	7-25-69	63	16	8	8	13	7
S-1	6-4-69	52	8	5	8	5	13
S-2	7-16-69	72	34	10	5	8	22
W-1	6-1-69	68	21	6	13	11	24
W-2	7-18-69	40	20	9	5	8	11

Table 13.

Time period & burn date	Unit exposure	Duff			Slash			Unit
		Lower	Upper		Needles	0-1 cm	1-10 cm	
May 16-31								
5-18-68	S	99+	[illegible]	[illegible]	[illegible]	11	21	[illegible]
Jun 1-15								
6-6-68	W	[illegible]	99+	[illegible]	[illegible]	[illegible]	19	[illegible]
6-1-69	S	68	21	[illegible]	[illegible]	11	24	[illegible]
6-4-69	A	[illegible]	8	5	[illegible]	[illegible]	11	[illegible]
Jun 16-30								
6-18-68	S	[illegible]	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Jul 1-15								
7-3-68	S	99+	71	7	[illegible]	[illegible]	[illegible]	[illegible]
7-5-68	E	[illegible]	76	5	[illegible]	[illegible]	[illegible]	[illegible]
7-8-68	S	99+	[illegible]	[illegible]	[illegible]	[illegible]	17	11
7-9-69	E	[illegible]	[illegible]	[illegible]	[illegible]	11	[illegible]	[illegible]
7-14-69	S	54	17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Jul 16-31								
7-18-67	E	54	48	[illegible]	[illegible]	17	[illegible]	[illegible]
7-27-67	W	94	47	4	[illegible]	12	[illegible]	[illegible]
7-16-68	W	78	41	[illegible]	[illegible]	7	[illegible]	[illegible]
7-18-68	E	99+	77	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7-24-68	W	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]
7-26-68	S	76	67	[illegible]	[illegible]	10	17	[illegible]
7-16-69	S	[illegible]	34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7-18-69	W	40	[illegible]	[illegible]	[illegible]	8	11	[illegible]
7-25-69	S&L	68	16	8	[illegible]	[illegible]	7	19
Aug 1-15								
8-3-67	N	51	34	[illegible]	5	[illegible]	25	21
8-8-67	S	28	43	[illegible]	24	19	[illegible]	24
8-7-68	E	85	54	[illegible]	6	[illegible]	[illegible]	54
Aug 16-31								
8-23-67	E,SE,W	[illegible]	24	5	4	[illegible]	[illegible]	[illegible]
8-24-67	W	56	24	[illegible]	4	[illegible]	18	[illegible]
8-30-68	W	99+	[illegible]	50	[illegible]	17	[illegible]	[illegible]
8-31-68	W	99+	67	25	[illegible]	[illegible]	[illegible]	39
Sep 1-15								
9-5-68	W	99+	99+	[illegible]	12	[illegible]	[illegible]	[illegible]
9-9-68	E	99+	55	[illegible]	13	[illegible]	17	[illegible]
9-10-68	[illegible]	99+	81	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sep 16-30								
9-30-68	S,W	99+	[illegible]	20	18	[illegible]	[illegible]	43
Oct 1-15								
10-2-67	E	70	94	[illegible]	[illegible]	[illegible]	[illegible]	39
10-5-67	S	77	99+	68	[illegible]	15	[illegible]	47
10-7-67	W	52	89	[illegible]	11	17	17	[illegible]
10-9-67	N	99+	[illegible]	[illegible]	6	[illegible]	[illegible]	[illegible]
10-9-67	W	[illegible]	24	5	1	[illegible]	[illegible]	19
10-10-67	E	[illegible]	99+	36	10	[illegible]	[illegible]	[illegible]
10-2-68	E	99+	97	27	15	17	24	[illegible]
10-3-68	N	99+	[illegible]	26	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX D: WEATHER SUMMARIES

Part I: Miller Creek, 1967

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
							JUNE									
Precipitation (inches)	--	0.02	0.59	0.11	--	--	0.50	0.18	0.25	0.08	--	0.03	--	--	--	0.03
Minimum humidity (percent)	46	34	80	47	22	34	41	60	73	56	37	52	38	27	27	35
Maximum temperature (°F)	70	59	43	54	66	62	66	56	55	54	56	52	60	71	74	77
Fine fuel moisture	19	17	18	9	5	6	8	11	14	10	8	10	6	4	4	6
Buildup Index	32	34	16	18	21	24	17	11	11	12	14	16	19	23	27	30

	Date														
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
							JUNE								
Precipitation (inches)	--	0.37	--	--	1.25	0.50	--	--	--	--	--	--	--	--	3.91
Minimum humidity (percent)	38	58	33	28	29	70	38	54	40	29	48	30	16	22	
Maximum temperature (°F)	72	63	73	78	77	61	60	58	68	74	67	72	72	70	
Fine fuel moisture	6	9	5	4	19	30+	19	27	19	16	18	15	14	14	
Buildup Index	33	23	26	30	6	5	1/ 17	17	19	22	24	27	31	35	

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
							JULY									
Precipitation (inches)	--	--	--	--	0.02	--	--	0.04	--	--	--	--	--	--	--	--
Minimum humidity (percent)	27	31	33	25	28	24	30	32	28	28	31	25	33	16	23	18
Maximum temperature (°F)	72	78	81	76	73	74	71	69	64	71	78	85	88	80	78	83
Fine fuel moisture	15	15	16	15	15	10	13	9	8	5	5	4	5	4	4	4
Buildup Index	38	41	44	47	50	53	56	58	60	63	66	70	73	78	82	86

	Date															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
							JULY									
Precipitation (inches)	T	--	--	--	0.01	--	--	--	--	--	--	--	--	--	--	07
Minimum humidity (percent)	24	18	35	43	31	32	19	23	24	22	25	13	13	24	38	
Maximum temperature (°F)	70	75	73	77	70	72	77	82	78	80	82	86	80	78	73	
Fine fuel moisture	10	4	4	8	5	5	4	4	6	6	6	6	3	5	5	
Buildup Index	87	90	93	95	98	101	105	109	112	115	118	121	126	130	133	

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
AUGUST																
Precipitation (inches)	--	--	--	--	--	--	0.01	--								
Minimum humidity (percent)	19	18	24	20	14	30	50	33	30	22	25	22	17	13	18	18
Maximum temperature (°F)	74	79	82	86	81	76	63	71	77	85	85	86	86	86	87	87
Fine fuel moisture	4	4	4	4	3	3	8	6	5	4	4	3	3	3	3	3
Buildup Index	137	142	146	151	156	159	161	164	167	172	176	181	188	195	200	205

	Date															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
AUGUST																
Precipitation (inches)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.01
Minimum humidity (percent)	13	13	17	16	26	19	20	--	21	--	--	36	--	--	19	
Maximum temperature (°F)	90	89	89	87	77	79	80	--	75	80	78	77	86	86	85	
Fine fuel moisture	3	2	3	3	5	4	4	4	4	4	6	6	4	4	3	
Buildup Index	210	217	222	227	230	235	239	243	247	251	255	258	262	266	271	

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SEPTEMBER																
Precipitation (inches)	--	--	--	-	T	--	--	--	--	0.30	--	-	--	--	--	
Minimum humidity (percent)	10	38	34	23	21	30	32	23	29	14	64	30	25	22	22	22
Maximum temperature (°F)	90	69	78	85	90	72	80	79	78	74	51	57	66	74	77	75
Fine fuel moisture	2	6	6	4	1	5	1	5	4	6	18	7	6	4	4	4
Buildup Index	278	281	284	288	292	295	299	302	307	310	310	312	315	319	323	327

	Date															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total	
SEPTEMBER																
Precipitation (inches)	--	--	--	--	--	--	--	-		--	--	--	--	--	.30	
Minimum humidity (percent)	22	28	32	25	21	14	14	14	20	28	28	15	26	38		
Maximum temperature (°F)	70	72	76	79	83	68	71	77	73	69	74	82	75	56		
Fine fuel moisture	4	4	6	4	4	4	3	4	4	6	4	5	6	8		
Buildup Index	331	335	338	342	347	351	356	361	365	368	372	379	382	384		

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
OCTOBER																
Precipitation (inches)	--	0.21	0.21	--	--	--	--	--	--	--	0.21	0.14	0.25	0.10	--	--
Minimum humidity (percent)	75	46	74	34	30	62	50	25	35	40	68	48	76	80	70	71
Maximum temperature (°F)	44	46	41	52	53	46	49	66	65	63	58	47	39	44	45	56
Fine fuel moisture	30+	10	18	9	9	14	14	6	6	8	25	10	30+	18	21	7
Buildup Index	384	116	69	71	73	74	75	78	81	83	58	51	42	42	42	44

1/ Adjusted for missing data.

	Date															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
							OCTOBER									
Precipitation (inches)	--	--	0.30	--	T	--	0.24	--	0.20	--	0.72	--	--	--	0.05	2.63
Minimum humidity (percent)	53	37	48	42	29	62	67	61	62	43	48	54	50	61	50	
Maximum temperature (°F)	55	57	43	50	49	40	40	49	40	41	40	44	39	38	54	
Fine fuel moisture	10	10	12	8	30+	30+	14	25	16	10	30	25	16	30	30	
Buildup Index	46	47	38	40	40	40	31	31	31	32	12	12	12	12	12	

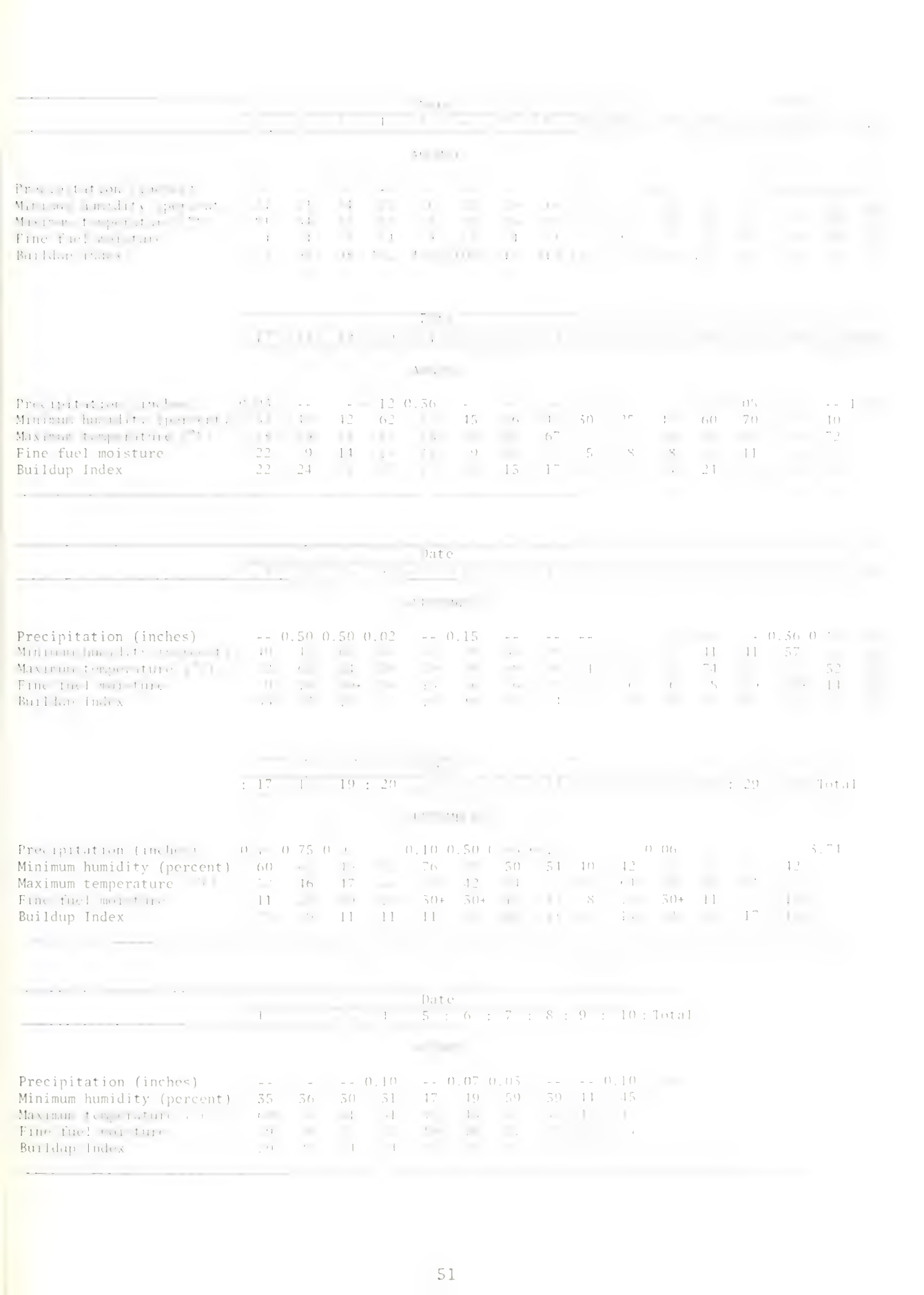
Part II: Miller Creek, 1968

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
							JUNE									
Precipitation (inches)		-	0.14	--	--	0.02	0.32	0.09	--	--	0.56	--	--	0.70	0.10	--
Minimum humidity (percent)	43	49	34	41	36	51	81	54	56	56	56	32	50	74	66	31
Maximum temperature (°F)	62	62	58	61	67	57	54	61	61	64	64	57	50	48	52	67
Fine fuel moisture	14	23	18	19	17	23	30+	19	24	22	19	18	24	30+	25	16
Buildup Index	12	13	12	14	16	17	12	14	15	16	11	13	14	6	7	10

	Date														
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
							JUNE								
Precipitation (inches)	-	--	--	--	--	0.18	0.19	--	--	--	0.07	0.07	0.20	0.41	3.05
Minimum humidity (percent)	33	30	-	--	--	--	--	--	--	10	28	40	82	96	
Maximum temperature (°F)	66	74	--	--	--	--	--	--	--	80	67	52	44	49	
Fine fuel moisture	17	16	16	18	17	30+	30+	20	19	13	18	20	30+	30+	
Buildup Index	12	15	18	20	18	16	16	17	19	24	26	27	26	18	

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
							JULY									
Precipitation (inches)		-	--	--	--	--	--	0.01	--	--	0.01	0.06	--	--	--	--
Minimum humidity (percent)	32	32	20	20	22	26	16	34	26	28	34	52	30	40	51	32
Maximum temperature (°F)	64	74	81	85	85	84	88	84	86	79	81	67	63	63	61	68
Fine fuel moisture	13	10	9	8	9	12	8	10	9	10	11	19	11	13	15	12
Buildup Index	20	23	27	32	36	38	43	46	50	54	57	58	61	63	64	66

	Date															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
							JULY									
Precipitation (inches)	--	--	--	0.28	--	--	--	--	--	--	--	--	--	--	--	.36
Minimum humidity (percent)	38	36	26	60	38	30	46	26	24	24	24	24	24	42	38	
Maximum temperature (°F)	63	68	77	54	66	70	66	73	77	80	83	84	76	64	71	
Fine fuel moisture	12	13	10	16	13	11	15	11	10	10	10	10	10	13	11	
Buildup Index	68	70	74	55	57	60	61	64	67	70	74	78	82	84	87	



Part III: Newman Ridge, 1969

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
JUNE																
Precipitation (inches)	--	--	--	--	--	0.05	--	--	--	--	0.15	--	--	--	--	--
Minimum humidity (percent)	28	34	30	23	40	56	58	40	45	31	24	86	30	21	24	21
Maximum temperature (°F)	68	72	78	85	73	71	63	71	72	66	74	46	59	67	69	71
Fine fuel moisture	16	16	15	13	18	30+	20	16	18	16	15	30+	17	15	16	15
Buildup Index	18	21	24	29	31	31	33	36	38	41	43	43	45	48	51	54

	Date															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total	
JUNE																
Precipitation (inches)	--	--	0.10	--	0.05	0.21	0.51	0.16	0.19	0.09	0.09	0.01	0.02	--	1.63	
Minimum humidity (percent)	25	28	32	46	61	62	72	74	66	84	60	58	70	28		
Maximum temperature (°F)	75	79	78	70	59	55	55	46	44	44	52	50	53	65		
Fine fuel moisture	15	15	15	19	24	21	24	28	30+	30+	24	23	25	16		
Buildup Index	57	60	63	65	66	49	23	21	21	21	22	23	24	27		

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
JULY																
Precipitation (inches)	--	--	0.23	--	--	--	0.07	--	--	--	--	--	--	--	--	--
Minimum humidity (percent)	26	45	65	45	58	34	40	37	28	30	37	45	26	36	30	27
Maximum temperature (°F)	73	71	50	59	57	64	65	66	75	78	64	60	66	65	68	72
Fine fuel moisture	11	19	22	15	16	11	16	13	10	10	15	15	11	13	11	10
Buildup Index	31	33	26	27	28	31	32	34	38	42	43	44	47	49	52	56

	Date																
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total	
JULY																	
Precipitation (inches)	--	--	--	--	--	-	--	--	--	--	--	--	--	--	--	.30	
Minimum humidity (percent)	30	26	20	29	29	30	30	36	36	40	30	18	20	16	20		
Maximum temperature (°F)	74	76	81	80	77	76	81	78	79	65	74	80	76	82	80		
Fine fuel moisture	10	10	8	10	10	10	10	11	11	13	10	8	10	8	9		
Buildup Index	59	63	68	72	75	78	82	85	88	90	93	98	102	107	111		

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
AUGUST																
Precipitation (inches)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Minimum humidity (percent)	20	20	16	22	33	28	20	26	20	28	26	43	28	24	34	30
Maximum temperature (°F)	82	83	78	80	57	70	76	76	81	82	80	62	75	82	78	63
Fine fuel moisture	8	8	8	9	12	10	11	10	8	9	10	13	10	8	10	11
Buildup Index	116	121	126	130	132	136	139	143	148	152	156	158	161	166	169	172

	Date															
	17	18	19	20	21	22	23	24	25	26	27	28	29			Total
						AUGUST										
recipitation (inches)			--	--	-	--					-	--		--		.00
inimum humidity (percent)	22	31	37	24	32	15	16	1	28	32	37	48	30	1	27	
aximum temperature (°F)	74	70	70	74	88	92	96	91	72	74	66	86	8	70	74	
ine fuel moisture	10	10	11	10	7	5	3	5	5	4	6	4	6	6	8	
uildup Index	176	179	182	186	191	196	201	206	209	213	216	219	22	3	229	

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
						SEPTEMBER										
recipitation (inches)	-	-	-	-	-	-	-	-	-	-	-	--	0.09	-	-	-
inimum humidity (percent)	22	29	46	74	40	25	22	38	24	26	46	38	46	69	70	26
aximum temperature (°F)	84	78	54	45	57	71	84	78	81	82	81	80	64	54	60	69
ine fuel moisture	4	5	10	17	8	6	4	5	5	6	6	6	11	8	5	4
uildup Index	234	237	238	238	240	243	248	251	253	256	259	262	265	68	68	71

	Date															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30		Total
						SEPTEMBER										
recipitation (inches)	--	0.10	0.03	0.22	0.02	--	0.42	0.11	0.02	--	0.00		0.06	0.6		1.78
inimum humidity (percent)	30	40	70	74	67	46	45	62	54	42	41	71	56	58		
aximum temperature (°F)	74	60	55	48	53	52	51	51	55	59	65	65	65	47		
ine fuel moisture	5	11	21	21	15	10	15	17	10	10	10	10	8	25		
uildup Index	274	275	155	86	87	38	41	44	45	46	47	48	50	52		

	Date															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
						OCTOBER										
recipitation (inches)	0.32	--	0.04	-		-	-	0.20	0.10		-					
inimum humidity (percent)	60	65	56	40	52	60	50	74	74	81	44	45	41	37	43	43
aximum temperature (°F)	49	42	46	48	44	49	57	55	40	38	40	54	57	45	45	44
ine fuel moisture	30	15	17	10	12	15	9	21	50	25	11	11	15	8	9	10
uildup Index	15	16	16	18	19	20	22	21	23	21	22	25	24	26	28	29

	Date												
	17	18	19	20	21	22	23	24	25	26	27	28	Total
						OCTOBER							
recipitation (inches)	--	--	--	--	--	--	0.29	0.25	-		0.04	0.08	
inimum humidity (percent)	38	31	40	60	40	29	45	67	75	69	70	65	
aximum temperature (°F)	50	50	47	50	64	67	56	44	52	50	48	45	
ine fuel moisture	9	8	10	13	8	6	15	30	18	23	25	24	
uildup Index	31	33	35	36	38	37	39	39	39	39	26	28	

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STAND STRUCTURE AND SUCCESSIONAL STATUS OF TWO SPRUCE-FIR FORESTS IN SOUTHERN UTAH

Donald P. Haniey,
Wyman C. Schmidt, and
George M. Blake

USDA Forest Service
Research Paper INT-176

INTERMOUNTAIN FOREST AND RANGE
EXPERIMENT STATION

THE AUTHORS

Idaho, is currently working on intensive culture of western redcedar and western hemlock and grand fir habitat types of northern Idaho, in cooperation with the Intermountain Station. Mr. Hanley holds B.S. and M.S. degrees in Forestry from the University of Montana.

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WYMAN C. SCHMIDT is a research silviculturist and leader of the Silviculture of Northern Rocky Mountain Larch, Lodgepole Pine, and Spruce Ecosystems research unit at the Forestry Sciences Laboratory, Bozeman, Montana. He joined the Intermountain Station in 1960 and has worked primarily in research of young coniferous forests. He holds B.S. and M.S. degrees in Forest Management and is currently completing requirements for the Ph.D. in Forest Ecology at the University of Montana.

GEORGE M. BLAKE, professor of silviculture at the School of Forestry, University of Montana, joined the University in 1962 and has worked in research of the Coniferous Ecosystems of the Northern Rocky Mountains. He holds a B.S. degree in Forestry from the University of Idaho and M.S. and Ph.D. degrees in forest genetics from the University of Minnesota.

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1975

STAND STRUCTURE AND SUCCESSIONAL STATUS OF TWO SPRUCE-FIR FORESTS IN SOUTHERN UTAH

Donald P. Hanley,
Wyman C. Schmidt, and
George M. Blake

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

ABSTRACT

Knowledge of the age-class distribution in the spruce-fir forests on the plateaus of southern Utah is necessary to prescribe silvicultural systems compatible with the ecological requirements of the species. Engelmann spruce, Picea engelmannii (Parry); subalpine fir, Abies lasiocarpa (Hook.) Nutt.; and quaking aspen, Populus tremuloides (Michx.), constitute the majority of the stands found on these high-elevation sites. Random samples of ages and diameters by species were analyzed from two stands on adjacent plateaus. Both stands are uneven-aged. Engelmann spruce, the primary species, is predominantly all-aged; subalpine fir is uneven-aged, but not all-aged; and aspen is even-aged. This age-class structure suggests the need for testing an uneven-aged silvicultural system in the management of these forests.

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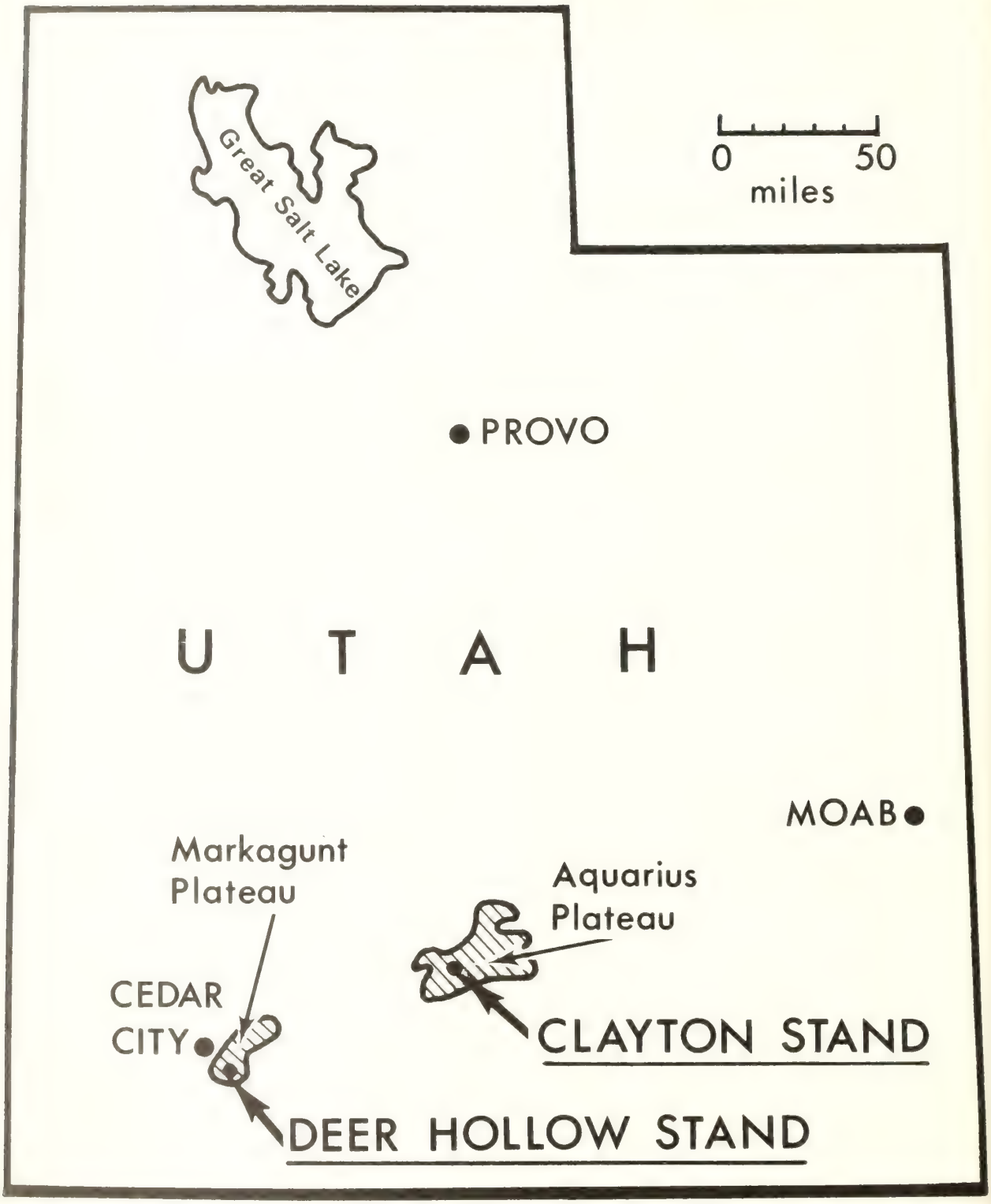


Figure 1.--Clayton stand and Deer Hollow stand study area locations.

INTRODUCTION

Engelmann spruce, *Picea engelmannii* (Parry), and subalpine fir, *Abies lasiocarpa* (Hook.) Nutt., forests cover vast areas of the subalpine zone in the Rocky Mountains the western United States and Canada. Both species grow in a cold, humid climate, aracterized by cool summers, very cold winters, and heavy snowfall (Sudworth 1916). though these high-elevation forests usually abut the timberline, they are also found favorable environments at lower elevations. A review of past literature reveals eat differences in the biotic and abiotic components of the spruce-fir type as one averses from north to south along the range of the species (Roe and others 1970).

Stand structure apparently varies similarly throughout the type, with researchers porting both even-aged and uneven-aged conditions. Bloomberg (1950) and Smith (1954) ported broadly even-aged structure in the spruce-fir forests of Alberta and British lumbia, while Day (1972) reported irregular to uneven-aged stands in southwestern berta where fire is infrequent. Hornibrook (1942), Miller (1970), and Alexander (1971) ported that the spruce-fir forests in Colorado are composed of even-aged stories inter-ngled on the same site. In recent publications, Alexander (1974) and Landis (1974) ported uneven-aged "multistoried" stands in Colorado. Mielke (1950) and Pfister 972), through analysis of stump ages and diameter distributions, concluded that spruce-r forests of southern Utah appear to be uneven-aged. Thus, it seems that age-class ructure of spruce-fir forests depends upon the specific location and its environ-ntal conditions.

Variable spruce-fir age-class structures have strong ecological and silvicultural plications that may help explain prompt or delayed regeneration throughout these rests. In general, the spruce-fir forests of the Rocky Mountains on lower elevation, rthern latitude sites have been the easiest to regenerate and forests on the higher evation, southern latitude sites, the most difficult to regenerate (Roe and Schmidt 64). Persistent difficulties in establishing natural regeneration with even-aged earcutting methods on spruce-fir sites in southern Utah raised an important question: e the silvicultural systems being employed compatible with natural stand succession? is study, conducted on the Aquarius and Markagunt Plateaus (fig. 1), is aimed at termining the stand structure and natural successional development in the high-evation spruce-fir forests of southern Utah. This paper suggests silvicultural stems most compatible with the natural establishment and development requirements these important forests.

STUDY AREA DESCRIPTIONS

Two high plateaus, with stands typical of the spruce-fir forests in southern Utah, were selected for this study. The Clayton stand on the Aquarius plateau and the Deer Hollow stand on the Markagunt plateau provided the sample base. These two stands are also the location of detailed spruce regeneration studies.[1] Thunderstorms and orographic lifting are the major precipitation sources throughout the short growing season, resulting in high-intensity storms almost daily (Farmer and Fletcher 1971). Snow accumulates at depths up to 12 feet, with some snow remaining in microsites well into June.

The Clayton stand (fig. 2) located in the center of the Aquarius Plateau, (200 air miles south of the Great Salt Lake) at 10,300 feet elevation is felt to be representative of the *Abies lasiocarpa/Ribes montigenum* habitat type (*Ribes* phase) (Pfister 1972). Approximately one-half of the subalpine forests of Utah are composed of this habitat type (Pfister 1972). Soils are a gravelly loam derived from andesite parent material (Pfister 1972).

The Deer Hollow stand, located on the southwestern edge of the Markagunt Plateau at 9,300 feet elevation, is approximately 70 air miles southwest of the Clayton stand. Deer Hollow represents a warmer climate than the other stand, as indicated by the *Abies lasiocarpa/Berberis repens* habitat type (*Ribes* phase) (Pfister 1972). Soils are a stony clay loam derived from Wasatch limestone (Pfister 1972).

[1]Pfister, Robert D., and Donald P. Hanley. Intermt. For. and Range Exp. Stn., Missoula, Mont. (Manuscript in preparation.)

METHODS

Ten sample plots, consisting of three concentric circular subplots of 1/100, 1/20, and 1/10 acre, were randomly selected at both Clayton and Deer Hollow (Hanley 1973). Tree sampling was based on diameter class (at 1 foot above ground level). The smallest individuals were sampled in the smallest subplot, and the intermediate and largest trees were sampled in the larger subplots, as follows:

Tree size classes	*Spruce*	*Fir*	*Aspen and others*
1-ft ht., 2-in. diam.	1/20	1/100	1/20
2 to 6-in. diam.	1/20	1/20	1/20
6 to 10-in. diam.	1/20	1/10	1/10
10+-in. diam.	1/20	1/10	1/10

All trees 2 inches in diameter and larger were aged at 1 foot in height by extracting increment cores. Disks were cut at ground line and at 1 foot above ground line from trees that were less than 2 inches in diameter for age analyses. Modal age values required to achieve 1 foot in height were derived from the disks of the small trees and were added to the increment core values of the larger trees to arrive at a total tree age. Modal age values were used because median or mean values would have adversely weighted the results toward very suppressed individuals which likely do not represent initial growth rates for larger trees now present. Modal age values had an average standard deviation of 9 years and are as follows:

	Clayton stand	*Deer Hollow stand*
Engelmann spruce	9	10
Subalpine fir	8	10

Heart rot incidence was determined for all trees measured. Site index was based on spruce site curves (Alexander 1967) and determined by selecting three dominant crown position spruce trees at each plot.

Uneven-aged stand, even-aged stand, and all-aged stand are commonly used for describing the age-class structure of forest stands. For clarity, we have adopted the definitions as stated by the Society of American Foresters (1971) as follows:

All-aged — A forest stand that contains trees of all or almost all age-classes, including those of exploitation age.

Even-aged — A forest stand composed of trees having no or relatively small differences in age. By convention, the maximum difference admissible is generally 10 to 20 years, though with rotations of less than or equal to 100 years, differences up to 30 percent of the rotation age may be admissible.

Uneven-aged — A forest stand composed of intermingling trees that differ markedly in age. By convention, a minimum range of 10 to 20 years is generally accepted, though with rotations of less than or equal to 100 years, 25 percent of the rotation age may be the minimum, in the United States.

The following chart may help clarify the definitions as used in the United States

An even-aged stand contains trees of one age group falling within 25 percent of the rotation length. An uneven-aged stand contains trees which fall in 2, 3, or 4 groups, each composed of 25 percent of the length of rotation. A theoretical all-aged stand is the ultimate uneven-aged condition.

RESULTS AND DISCUSSION

Diameter Distributions

Diameter distributions of spruce and fir were similar for both the Clayton and Deer Hollow stands (fig. 3 and 4). Both stands had large numbers of trees under 4 inches in diameter. The stand diameter distribution and a normal assumption of a diameter-age correlation (Hanley 1973) gives the stand the appearance of uneven-aged structure with both spruce and fir contributing to this condition. Aspen's *Populus tremuloides* (Michx.) diameter distribution curve, particularly at the Clayton site, approximated a normal probability curve--an even-aged distribution. Although evaluations of stand structure are often based only on diameter distributions (Smith 1962), a more precise evaluation is possible with actual age. The following analyses of tree ages found in these stands were used to confirm or reject the first impressions obtained from diameter distributions.

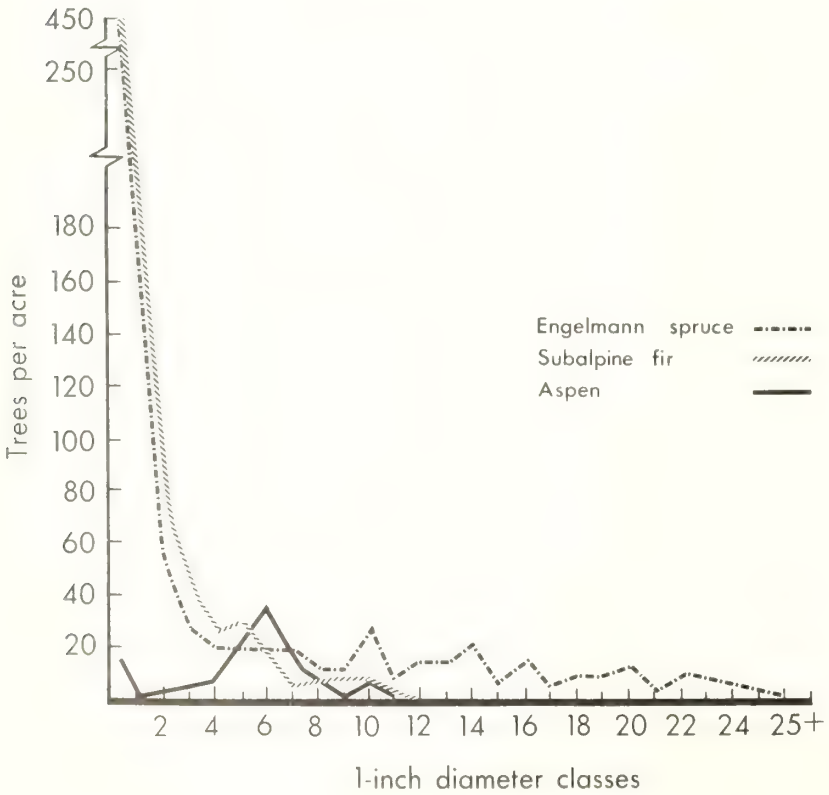
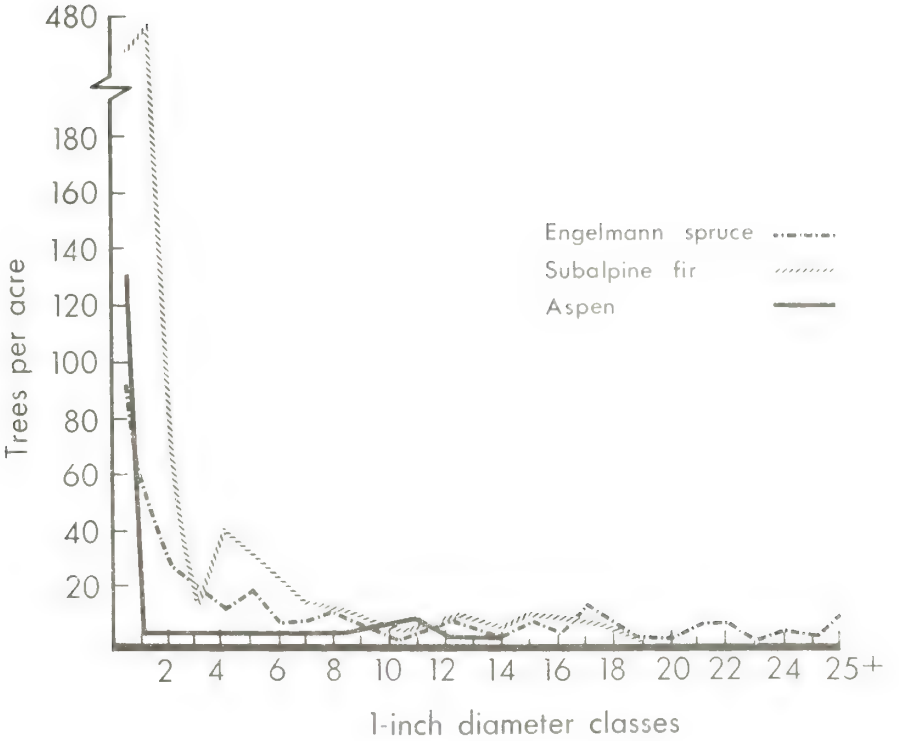


Figure 3.--Clayton stand diameter distribution.

igure 4.--Deer Hollow stand diameter distribution.



Age-Class Distributions

Age-class structure is a relative attribute of the stand because even-aged structure and all-aged structure are the theoretical endpoints to man's classification ystem. Thus, the determination of age-class structure is a matter of interpretation, ombining the knowledge of the age distribution and successional trends acting on the ite. The structures discussed here follow the qualitative definitions presented in he introduction.

layton Stand

Spruce ages at Clayton were distributed along a decreasing function curve characeristic of all-aged structure (fig. 5). Because of waves of spruce reproduction stablished about 50 and 130 years ago, this stand was not perfectly regular. Reproduction waves are not incompatible with the all-aged concept because they are normal ttributes of a dynamic system (Jones 1945; Alexander 1958). However, the waves were ot large enough in the Clayton stand to constitute a storied forest appearance--no anopy stratification was evident.

Subalpine fir in the Clayton stand was uneven-aged, but not all-aged. Abundance f trees in the 30-, 40-, and 50-year age-classes indicated prolific reproduction during hese periods. For example, Dixon (1935) and Mielke (1950) reported an Engelmann spruce eetle *Dendroctonus engelmannii* (Hopk.) epidemic during the 1930 decade that possibly ltered the spruce canopy enough to favor subalpine fir reproduction. Subalpine fir eproduction by layering was probably also abundant. Additionally, the long "tail" of he curve (70 to 160 years) indicated that fir was able to maintain itself under the pruce canopy, expressing uneven-aged characteristics.

Because of the prevalence of heart rot, it was impossible to age aspen for a large roportion of the sample. However, clones appeared to be generally from 40 to 70 years n age. Although clones varied in age, most trees within each clone appeared to be the ame age. The even-aged clones were intermingled with the uneven-aged conifer stand.

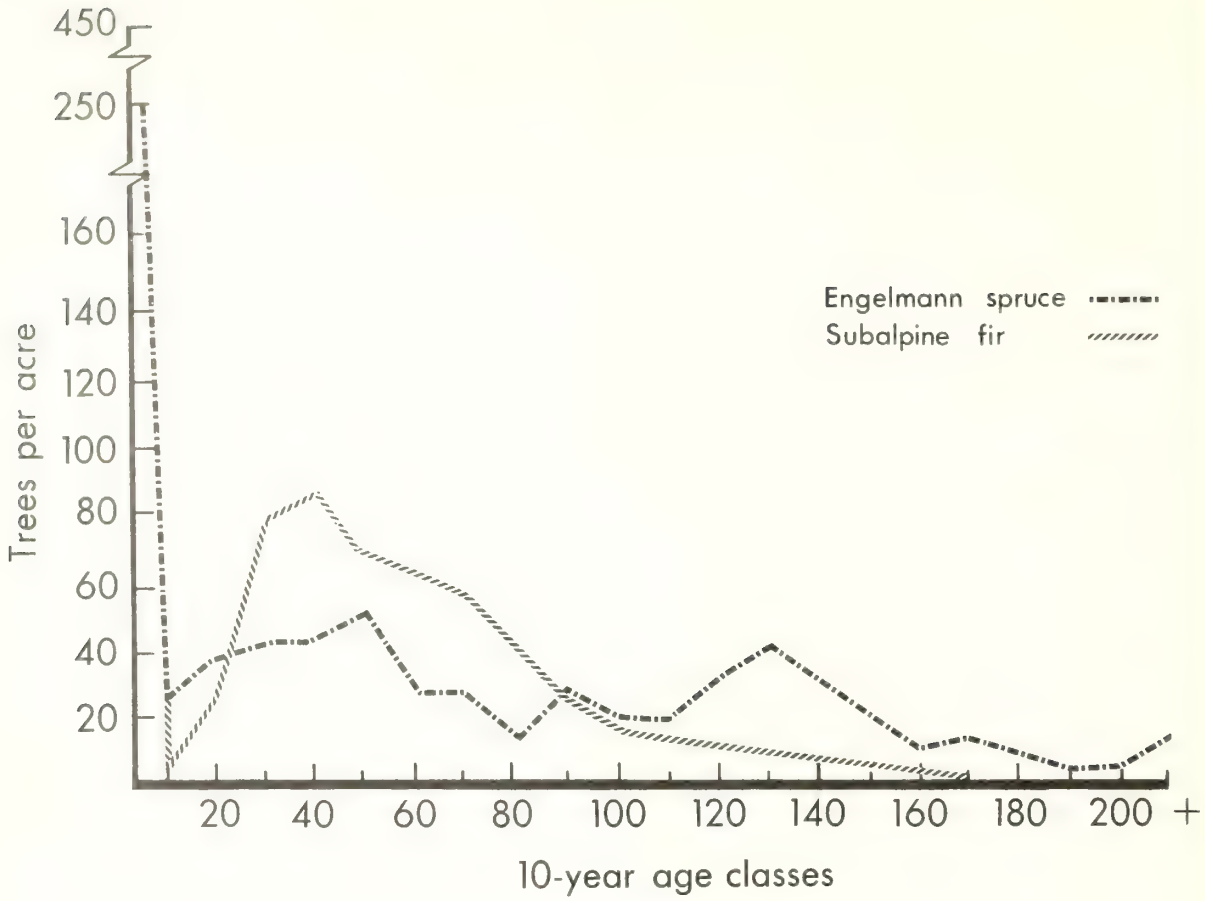
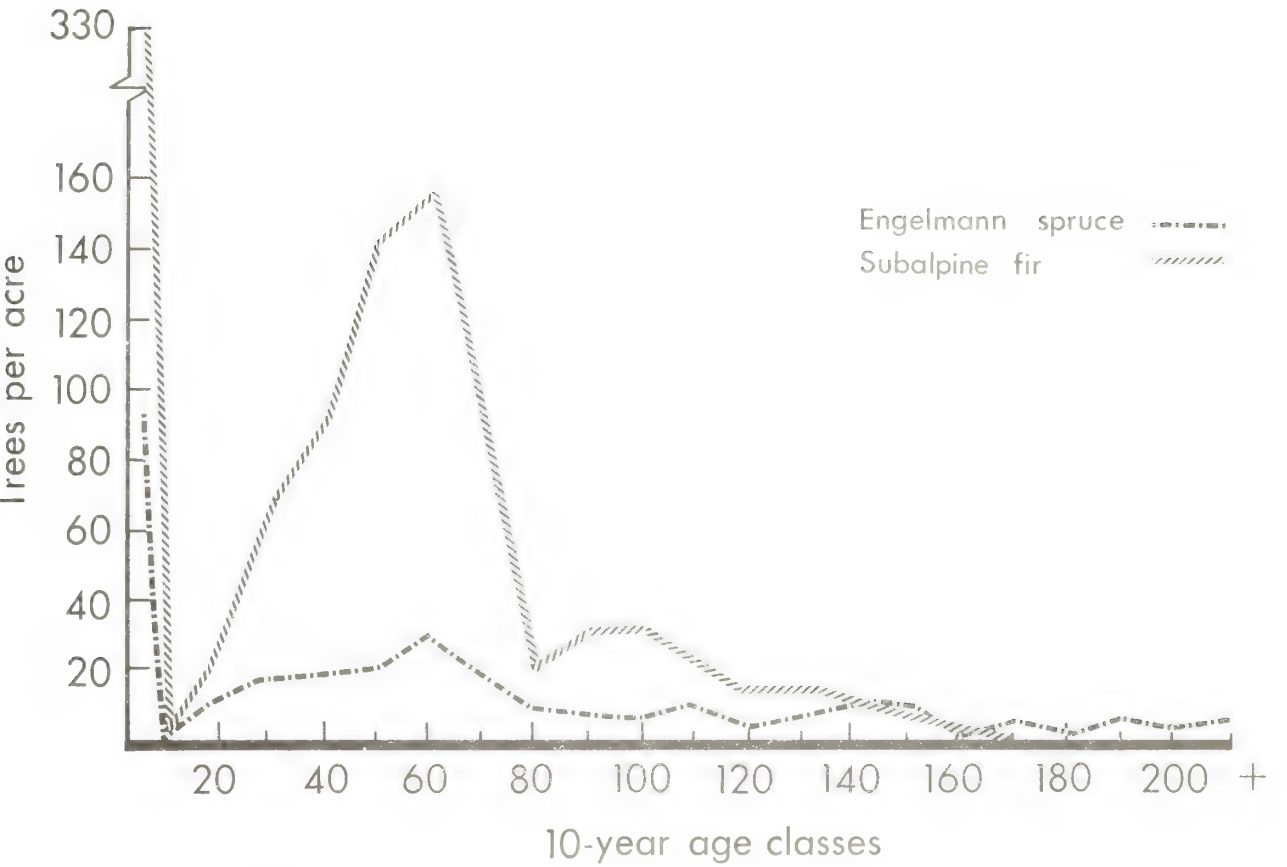


Figure 5.--Clayton stand age-class distribution, 1975.

The Deer Hollow stand followed much the same pattern as the Clayton stand, exhibiting an uneven-aged distribution (fig. 6). Spruce was distinctly all-aged, even though a few of the age classes were poorly represented, resulting in an irregular condition. Subalpine fir exhibited uneven-aged characteristics, with age classes of 20 to 80 well represented. Large variations in the age-distribution graph indicated that fir reproduced in waves under favorable conditions, supplementing uniform and sometimes irregular establishments at other times.

Very few seedlings were sampled in the 10-year age-class (early 1960's) at either Clayton or Deer Hollow (fig. 5 and 6). We cannot pinpoint the exact reason for the lack of reproduction during this time period. However, lack of both spruce and fir reproduction *could* have been caused by unfavorable weather conditions resulting in frost kill, frost heaving, rapid soil surface drying, and soil movement both in the open and under the existing canopy.[2] Engelmann spruce vigor could have been reduced at the Clayton stand by mealy bug *Puto sandini* (Washburn 1965), resulting in poor spruce seed crops. This, coupled with high populations of seed-eating rodents[2] could have contributed to the poor reproduction during this period.

[2]Op. cit.



Species Composition

Species composition varied between the study locations (table 1). At the Clayton stand, tree density was higher and species more evenly distributed. Deer Hollow tree density was dominated by subalpine fir, accounting for almost 70 percent of the stocking. Douglas-fir, [illegible] (James), were also present in the Deer Hollow stand as widely scattered individuals.

Heart rot and root-rotting fungi were prevalent (table 1). *Fomes annosus* (Pfister 1972), for subalpine fir, and *Fomes igivarius* (Frykman 1958), for aspen, appear to be the major fungi. Most aspens more than 8 inches d.b.h. had heart rot. Spruce was less affected by these rotting fungi.

Spruce and subalpine fir had large numbers of seedlings, with subalpine fir exceeding spruce about 2 to 1 in the small sizes. Subalpine fir gained this numerical advantage by being able to reproduce on duff-covered seedbeds (Roe and others 1970). It also gained additional stocking through its unique ability to reproduce by layering. Subalpine fir mats, up to 20 feet across, were occasionally observed on the study areas. The layered stems grew slowly, requiring up to 100 years to reach 1-inch diameter near the ground line.

Table 1.--*Species composition and percentage of heart rot of two stands in the spruce-fir type of southern Utah*

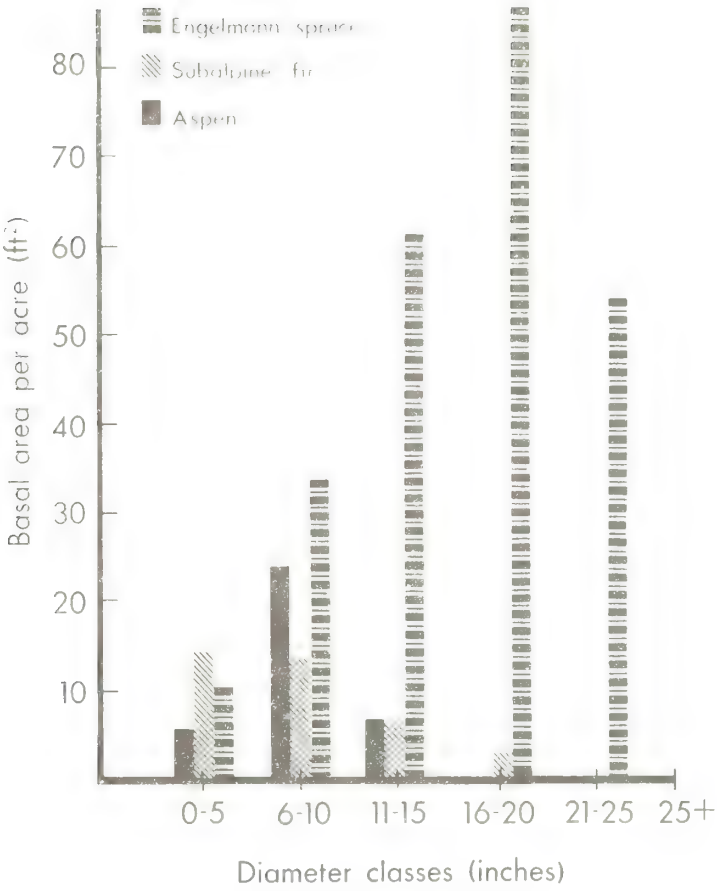
Tree species	Trees/acre	Species composition	Heart rot[1]
		Percent	
	CLAYTON STAND		
Engelmann spruce	746	40	11
Subalpine fir	975	52	10
Aspen	139	8	86
Total	1,860	100	
	DEER HOLLOW		
Engelmann spruce	308	20	5
Subalpine fir	1,042	69	8
Aspen	147	10	94
Limber pine	8	<1	25
Douglas-fir	1	<1	0
Total	1,506	100	

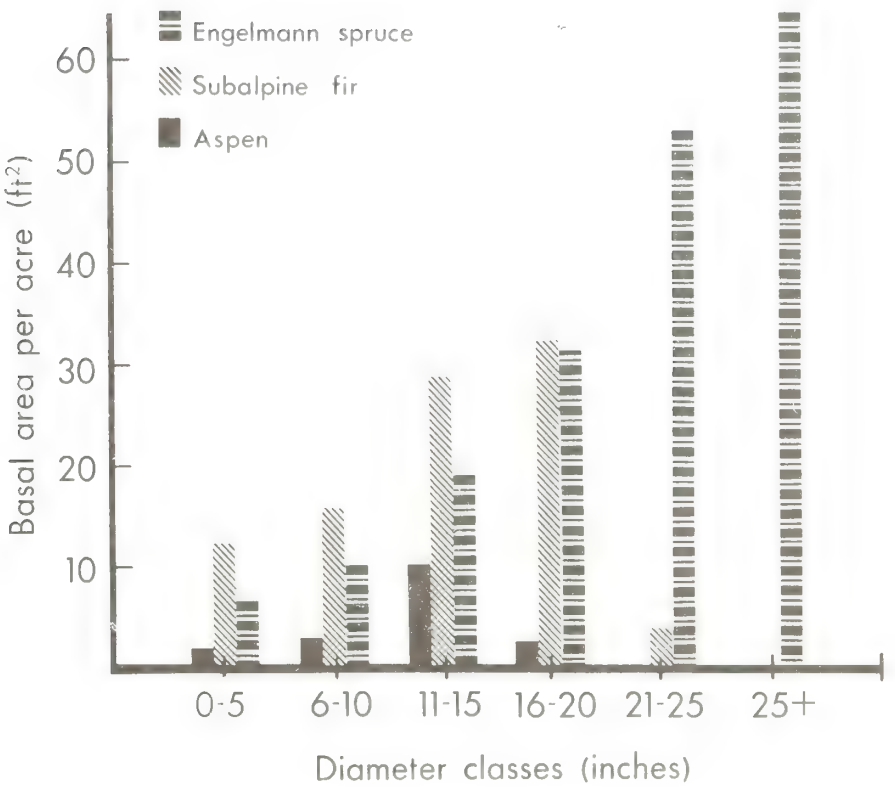
[1]Heart rot percentage by species is based on the number of trees 1 inch and larger in diameter.

Of total basal area, spruce accounted for 78 percent at the Clayton stand and, 62 percent at the Deer Hollow stand (fig. 7 and 8). Larger diameters and a greater proportion of large stems accounted for the higher spruce basal areas. Spruce trees at the Clayton stand averaged 0.33 square foot of basal area, while the larger spruce diameters at the Deer Hollow stand averaged 0.59 square foot basal area.

Subalpine fir accounted for 11 and 31 percent of the basal areas at the Clayton and Deer Hollow stands, respectively. Subalpine fir was characterized by high density but relatively low basal area at both stands due to the large proportion of medium and small diameters. Subalpine fir at the Clayton stand averaged 0.04 square foot basal area, while the larger diameters at the Deer Hollow stand averaged 0.09 square foot basal area.

Aspen accounted for the remaining 11- and 7-percent basal area at the Clayton and Deer Hollow stands, respectively. Variability of aspen basal area was high due to the clonal nature of the species.


Engelmann spruce
Subalpine fir
Aspen
Basal area per acre (ft²)
80
70
60
50
40
30
20
10
0-5
6-10
11-15
16-20
21-25
25+
Diameter classes (inches)


Engelmann spruce
Subalpine fir
Aspen
Basal area per acre (ft²)
60
50
40
30
20
10
0-5
6-10
11-15
16-20
21-25
25+
Diameter classes (inches)

Stand Successional Status

The Clayton stand appears to be at equilibrium with its environment, representing the climax vegetation. Subalpine fir and Engelmann spruce are coclimax species in the association. Spruce maintains its position in the overstory with an average longevity of 2 to 1 over the subalpine fir, reproducing in abundant quantities on favorable microsites, i.e., partial shade and mineral soil. Subalpine fir reproduces under the spruce canopy on a variety of seedbeds, but does not overtake the dominant crown position of the spruce. In other words, a subalpine fir may complete its entire life cycle under the shade of an older larger spruce.

Aspen, a seral species, becomes established as small clones after severe disturbances of the overstory. Examples of such disturbances are local epidemic insect populations, severe windthrow areas, and small localized lightning fires. Uneven-aged conifer reproduction occurs beneath the aspen, eventually succeeding it. Thus, the aspen clones serve as "nurse crops."

The role of aspen in the successional development of the Deer Hollow stand appears similar to the Clayton stand in that uneven-aged conifer reproduction was observed under the aspen clones (fig. 9). Larger aspen clones, up to 30 acres, and the "wavelike" nature of the subalpine fir reproduction under the clonal canopy suggest the possibility of a widespread disturbance at Deer Hollow approximately 60 years ago. This disturbance apparently altered the conifer canopy and allowed abundant aspen sprouting. The widespread disturbance to the conifer canopy could have been caused by bark beetles, windthrow, or fire. Windthrow and fire are good possibilities because the Deer Hollow stand is near the rim of the plateau where remnants of burned bark could be seen on surviving old-growth Douglas-fir trees.

Figure 9.--Uneven-aged conifer reproduction under the protection of an even-aged aspen clone.

SILVICULTURAL IMPLICATIONS

Silvicultural practices in the high-elevation spruce-fir forests must be based on sound ecological framework. Two important ecological factors stressed in this paper re the uneven-aged structure and the projected vegetation changes over time. In addition, studies of successional trends (Pfister 1972) and regeneration[3] of these *same* pruce-fir forests complement results from this study and, combined, provide the basis or the following recommendations:

1. An uneven-aged silvicultural system should be tested in similar southern Utah pruce-fir forests. Specifically, light group or individual tree selection methods ppear to mimic the natural dynamic condition affecting these forests, and we recomend that they be examined under regular management situations. These methods should rovide favorable microsites for conifer seedlings and prevent severe seedling mortalty from frost, desiccation, and soil movement. However, all traditional timber arvesting methods, including our recommendation, have some flaws when applied to these evere sites. Heavy partial cuts can result in severe windthrow, resulting in pidemic bark-beetle populations. Careful logging to minimize bole and root damage, ogether with high utilization standards and adequate slash treatment, would have to be ndertaken to reduce bark-beetle brooding sites.

2. If even-aged management is the goal of the land manager, the shelterwood ystem appears most compatible with these stand conditions and should be tested. The ogging precautions stated in recommendation 1 may be required to keep bark-beetle opulations in check. Pfister (1973) stated that clearcutting with planting may be n appropriate silvicultural method in the *Abies lasiocarpa/Berberis repens* habitat ype. We agree that this even-aged method is feasible *if* extreme care is taken in the ctual planting and site modification is provided to reduce the environmental extremes ound at the soil surface.[3] More study should be given to the use of aspen clones as urse crops in the regeneration of clearcuts.

The authors feel that the recommendations given are the most appropriate for mber management in these high-elevation spruce-fir forests. Participation of other orest disciplines, i.e., entomology, range, and wildlife, must be included in all hases of management planning and operations if the land management objectives are to e achieved.

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[3]Op. cit.

PUBLICATIONS CITED

lexander, Robert R.
1958. Silvical characteristics of Engelmann spruce. USDA For. Serv., Rocky Mt. For. and Range Exp. Stn. Res. Pap. 31, 20 p., Ft. Collins, Colo.

lexander, Robert R.
1967. Site indexes for Engelmann spruce in the central Rocky Mountains. USDA For. Serv. Res. Pap. RM-32, 7 p. Rocky Mt. For. and Range Exp. Stn., Ft. Collins, Colo.

lexander, Robert R.
1971. Initial partial cutting in old-growth spruce-fir. USDA For. Serv. Res. Pap. RM-76, 10 p., Rocky Mt. For. and Range Exp. Stn., Ft. Collins, Colo.

lexander, Robert R.
1974. Silviculture of subalpine forests in the central and southern Rocky Mountains: the status of our knowledge. USDA For. Serv. Res. Pap. RM-121, 88 p., Rocky Mountain For. and Range Exp. Stn., Ft. Collins, Colo.

loomberg, W. J.
1950. Fire and spruce. For. Chron. 26:157-161.

ay, Robert J.
1972. Stand structure, succession, and use of southern Alberta's Rocky Mountain Forest. Ecology 53:472-479.

ixon, Helen.
1935. Ecological studies on the high plateaus of Utah. Bot. Gaz. 97:272-320.

armer, Eugene E., and Joel E. Fletcher.
1971. Precipitation characteristics of summer storms at high elevation stations in Utah. USDA For. Serv. Res. Pap. INT-110, 24 p. Intermountain For. and Range Exp. Stn., Ogden, Utah.

rykman, Joel L.
1958. Aspen management in Utah. Proc. Soc. Am. For., Salt Lake City, Utah.

anley, Donald P.
1973. Stand structure of spruce-fir forests in southern Utah. M.S. Thesis, Univ. Mont., 76 p.

ornibrook, E. M.
1942. Yield of cutover stands of Engelmann spruce. J. For. 40:778-781.

ones, E. W.
1945. The structure and reproduction of the virgin forests of the North Temperate Zone. New Phytol. 44:130-148.

andis, Thomas D.
1974. Bole production and the environmental complex in subalpine spruce-fir stands in southwestern Colorado. Ph.D. Diss., Colo. State Univ., 96 p.

Mielke, James L.
1950. Rate of deterioration of beetle-killed Engelmann spruce. J. For. 48:882-888.
Miller, Phillip C.
1970. Age distributions of spruce and fir in beetle-killed forests on the White River Plateau, Colorado. Am. Midl. Nat. 83:206-212.
Pfister, Robert D.
1972. Vegetation and soils in the subalpine forests of Utah. Ph.D. Diss. Wash. State Univ., Pullman, Wash., 98 p.
Pfister, Robert D.
1973. Habitat types and regeneration, p. 120-125. *In* Permanent Assoc. Comm. Proc., West. For. & Conserv. Assoc., Portland, Oreg.
Roe, Arthur L., and Wyman C. Schmidt.
1964. Factors affecting natural regeneration of spruce in the Intermountain Region. USDA For. Serv., Intermt. For. and Range Exp. Stn., Mimeo. Rep. 68 p.
Roe, Arthur L., Robert R. Alexander, and Milton D. Andrews.
1970. Engelmann spruce regeneration practices in the Rocky Mountains. USDA For. Serv. Prod. Res. Rep. 115, 32 p.
Smith, David M.
1962. The practice of silviculture. 578 p. John Wiley & Sons, New York.
Smith, J. H. G.
1954. A cooperative study of Engelmann spruce subalpine fir silviculture and management. Northwest Sci. 28:157-165.
Society of American Foresters.
1971. Terminology of forest science, technology, practice and products. 349 p. Soc. Am. For., Washington, D.C.
Sudworth, G. B.
1916. The spruce and balsam firs of the Rocky Mountain Region. U.S. Dep. Agric. Bull. 327, 43 p. Washington, D.C.
Washburn, R. I.
1965. Description and bionomics of a new species of *Puto* from Utah. Annu. Ent. Soc. Am. 58(3):293-297.

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GROWING
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CHARACTERISTICS AND HYBRIDIZATION OF IMPORTANT INTERMOUNTAIN SHRUBS.

II. CHENOPOD FAMILY

A. Clyde Blauer, A. Perry Plummer,
E. Durant McArthur, Richard Stevens,
and Bruce C. Giunta

MAY 6 19

USDA Forest Service
Research Paper INT-177, 1976

INTERMOUNTAIN FOREST AND RANGE
EXPERIMENT STATION

CHARACTERISTICS AND HYBRIDIZATION OF IMPORTANT INTERMOUNTAIN SHRUBS. II. CHENOPOD FAMILY

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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

A. CLYDE BLAUER is an assistant professor of Life Sciences, Division of Natural Sciences, Snow College, Ephraim, Utah. He received his B.S. (1964) and M.S. (1965) degrees in botany from Brigham Young University. He has received additional postgraduate training at Cornell University in plant pathology and plant breeding (1965-66) and at the University of Alabama in algology (1973). Since 1967, he has done botanical work each summer for the Intermountain Station in Ephraim.

A. PERRY PLUMMER is project leader for the Shrub Improvement and Revegetation research unit for Intermountain Station at the Shrub Sciences Laboratory, Provo, Utah. He has worked in range research for the Station since 1936. He received his B.S. degree (1935) and his M.S. degree (1939) in botany from the University of Utah. His research has been principally concerned with restoration of western ranges.

E. DURANT McARTHUR is a research geneticist at Intermountain Station's Shrub Sciences Laboratory in Provo. His degrees are from the University of Utah: B.S. in genetics and cytology (1965), M.S. in molecular and genetic biology (1967), and Ph.D. in biology (1970). He was a postdoctoral research fellow of agricultural botany (1970-71) at the University of Leeds, United Kingdom. He joined the Station in 1972.

RICHARD STEVENS is a wildlife resources biologist for the Utah Division of Wildlife Resources stationed in Ephraim. He received his B.S. degree in range management (1965) from Brigham Young University and his M.S. degree in range management (1968) from the University of Arizona. From 1968 to 1969, he was a range conservationist with the USDA Forest Service. He has been in his present position since 1969.

BRUCE C. GIUNTA is a wildlife resources biologist for the Utah Division of Wildlife Resources. He has been stationed at Ephraim since 1971. He began work for the Division in 1969 as the wildlife management area supervisor for the Hardware Game Management Unit. He received both his B.S. in wildlife management (1963) and his M.S. in wildlife biology (1968) from Colorado State University.

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ABSTRACT

Chenopod shrubs as a group constitute a significant segment of the Intermountain area's vast shrub lands. In alkaline areas, they are the principal component of the vegetation. They are producers of forage, they provide cover and, most importantly, they stabilize xeric, mineral soils where few other plants are adapted. General characteristics--vegetative, floral, reproductive, hybridization, distribution and habitat, and use--are described and reviewed for Atriplex canescens, A. confertifolia, A. corrugata, A. cuneata, A. gardneri, A. obovata, Ceratoides lanata, Grayia brandegei, G. spinosa, Kochia americana subsp. vestita, K. prostrata, and Sarcobatus vermiculatus. Artificial hybridization studies indicate considerable interspecific gene exchange and at least some intergeneric hybridization are possible. A taxonomic key covering each taxon discussed is provided.

INTRODUCTION

Shrubby chenopods, commonly referred to as saltbushes, cover millions of [illegible] on the world's alkaline ranges. They are important on the arid deserts of northern America, interior Australia, Africa, and Eurasia. These shrubs are of special significance in the Great Basin and Colorado River Drainage where as a group they are often the dominant vegetation below 1,677 meters (5,500 feet) (Branson 1966).

On ranges where they occur, they are important producers of nutritious forage for game and domestic animals. More importantly, their presence is essential for maintaining a stable soil in highly xeric environments where the soil is too salty and dry for most other classes of plants to live (Gates and others 1956). This group of shrubs grows well in high concentrations of calcium and potassium salts, and can endure considerable sodium; some require it (Gates and others 1956; McNulty 1969; Moore and others 1972). Consequently, we must especially look to shrubby chenopods for stabilization of arid and alkaline soils disturbed by oil drilling, mining operations, and road and building construction, as well as for improving vast areas of arid ranges. Most shrubby chenopods supply adequate nutrition that adds greatly to their value in providing habitat for a multitude of animals, including domestic ones (Esplin and others 1937; Cook and others 1951; Cook 1972). Chenopods can provide the shrubby components that along with grasses and forbs give a balanced cover and diet (Plummer and others 1968).

Shrubby chenopods from different localities and sometimes from the same site vary considerably in palatability, growth rate, forage production, and other characteristics that make them important sources of browse and cover. Some should have an important place in stabilization of disturbed areas on alkaline ranges. Natural hybridization has been observed between species of the same genus and even between different genera.

The purpose of this paper is to document what is known about important chenopod shrubs in the Intermountain area, with regard to their vegetative and floral characteristics, hybridization, distribution and habitat, and use. Most of the observational information and experimental data were gathered from the Intermountain area (Holmgren and Reveal 1966), particularly from Utah. Holmgren and Reveal's Intermountain area "includes all of Utah, that portion of Arizona north of the Grand Canyon, most of Nevada, parts of California that lie within the Great Basin, the sagebrush areas of southeastern Oregon, southern Idaho to the high mountainous areas to the north, and the Red Desert area of southwestern Wyoming." However, reference to and comments on species distribution and characteristics outside this area are made when pertinent. This is done to provide a basis for extended use and improvement of this group by selection and hybridization. Since Utah is centrally located in the distribution of this family, observations are fairly characteristic of west-central North America.

Each species, its hybridization, distribution and habitat, and use are described in detail. Each genus and its included species are arranged in alphabetical order. A key (appendix) is given for the included genera and species. This paper is the second in a series on Intermountain shrub species; the first is Blauer and others (1975).

METHODS

A survey of literature, particularly of pertinent keys and monographs, was made ahead of intensive selection and breeding trials. In addition, field observations were made during the 1967 and subsequent growing seasons on floral and vegetative characteristics of the shrubs. Collections were made of most species in various stages of development for illustrative purposes. Where no data were available on the number of seeds per pound, the number was determined on the basis of 10 samples of 100 seeds each.

Artificial hybridization was attempted by treating pistillate bushes of *Atriplex canescens* with pollen from various species of *Atriplex*, *Grayia*, *Ceratoides lanata*, and *Sarcobatus vermiculatus* (fig. 1). These crosses were made to determine any major difficulties in interspecific hybridization within and between these closely related genera. Information regarding these crosses is presented in the following resumes for the species with which hybridization was performed.

Germination tests were conducted to determine viability of the seed produced from the crosses. For these tests, the seeds were placed on moistened newspapers or paper towels, which were then folded in half (fig. 2). The folded papers were covered by plastic sheets and placed in refrigerators maintained at temperatures between 1° and 3° C. Seeds that sprouted were transplanted to pint milk cartons and placed in greenhouses to develop (fig. 3).

Seedlings obtained from various crosses since 1968 were transplanted during the latter part of May 1971 at the Snow Field Station north of Ephraim, Utah.

Figure 1.--Pistillate fourwing saltbush (Atriplex canescens) *with bagged branches treated with pollen from different species of* Atriplex. *The same procedure was used when treating fourwing saltbush with pollen from* Grayia, Ceratoides, *and* Sarcobatus.

Figure 3.--Putative artificial fourwing saltbush hybrid seedlings.

SPECIES CHARACTERISTICS

Atriplex—Common Floral Characteristics

The *Atriplex* species discussed in this paper are largely dioecious, although monoecious plants are found in most populations.

The staminate flowers lack petals and bracts. They normally have five united sepals and five stamens borne opposite the calyx lobes (fig. 4 and 5). These male flowers are borne in small compact clusters called glomerules.

Figure 4.--Fourwing saltbush staminate flower in late bud. The calyx lobes have separated and exposed the anthers (X20).

Figure 5.--Fourwing saltbush staminate flower in late anthesis. The filaments have elongated and the anthers have dehisced (X20).

The pistillate flowers [illegible] of pistils, each subtended by [illegible] matures. The [illegible] species (Fig. 7).

Figure [illegible].

Figure [illegible]. -- [illegible]. Atriplex canescens, *(b)* A. confertifolia, *(c)* A. corrugata, *(d)* A. cuneata, *(e)* A. gardneri, *(f)* A. obovata, *(g)* A. canescens × A. confertifolia, *(h)* A. canescens × A. gardneri, *(i)* Ceratoides lanata, *(j)* [illegible], *(k)* [illegible], *(l)* Krascheninnikovia americana vestita, *(m)* [illegible], *(n)* Sarcobatus vermiculatus.

Atriplex canescens (fourwing saltbush)

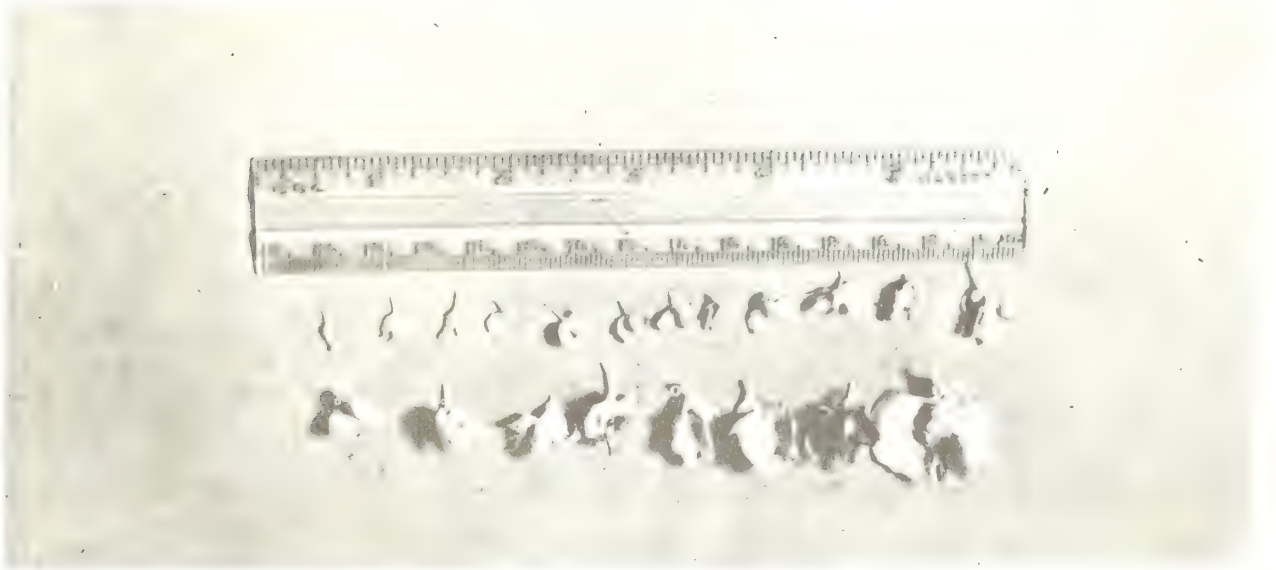
Fourwing saltbush is a shrub usually from 0.5 to 2.0 meters tall (fig. 8). It branches freely from the base, and the branches are usually quite brittle. Both the young twigs and the leaves are gray green because of the white, scurfy vestiture. The linear to oblanceolate or spatulate evergreen leaves are 1 to 4 cm long and 2 to 6 mm wide.

In fourwing saltbush populations he sampled, Hanson (1962) noted that as high as 3 percent of the plants were monoecious; however, we have observed populations in which the number of monoecious plants reached as high as 14 percent. A few populations may have no monoecious plants. Pistillate flowers are small and inconspicuous with no flower parts except pistils. Each pistil is enclosed by a pair of small bracts that are united along their edges to form winglike expansions. In addition, each bract of the pair has a wing down its middle; so the fruit (utricle) at maturity has a varying prominence of four wings (fig. 9). There is a high degree of variation in this characteristic, since some utricles are practically wingless. The yellow to red to brown male flowers are borne in glomerules 2 to 3 mm wide.

Fourwing saltbush blooms from May to July in the Upper Sonoran zone. In the Lower Sonoran zone, blooming occurs from July to August. Increase in elevation within zones delays flower development.

Utricles mature 14 to 16 weeks after flowering. They are usually persistent and can be harvested from mid-October through April (Benson and Darrow 1944; Plummer and others 1966a). Occasionally, utricles from the past two seasons can be found on bushes growing on drier sites. Dewinged utricles of this shrub average 55,365 per pound (122/g) (Plummer and others 1968). The utricle wings are removed by hammer milling and fanning.

Figure 8.--Pistillate fourwing saltbush showing highly branched habit and heavy utricle production.



Garrett saltbush (*Atriplex garrettii*), a form closely related to fourwing saltbush, also has four-winged utricles. It differs by being a subshrub under 40 cm tall with wider leaves, oval or broadly elliptical in shape.

The taxonomic status of Garrett saltbush is uncertain. Some authors (Hall and Clements 1923; Harrington 1954; Brown 1956) consider it a subspecies of fourwing saltbush. Other authors (Kearney and Peebles 1960; Hanson 1962; Plummer and others 1966b) accept it as a separate species. Garrett saltbush is a narrow endemic. It occurs only along the Colorado River and its tributaries in southern Utah and closely adjoining areas.

Hybridization: Fourwing saltbush readily hybridizes in nature with other *Atriplex* species (Hanson 1962; Plummer and others 1957; Plummer and others 1966a; Drobnick and Plummer 1966), (fig. 10 and 11). Our preliminary results and the results of Drobnick and Plummer (1966) indicate that artificial pollination of pistillate fourwing saltbush with pollen from shadscale saltbush (*Atriplex confertifolia*), Gardner saltbush (*A. gardneri*) (fig. 12), mat saltbush (*A. corrugata*), winterfat (*Ceratoides lanata*), black greasewood (*Sarcobatus vermiculatus*), spiny hopsage (*Grayia spinosa*), and spineless hopsage (*G. brandegei*) has resulted in viable seed. It is not known whether this pollination produces genuine hybrid seed in all cases. It may stimulate asexual reproduction in which seeds develop from unfertilized eggs or from somatic cells associated with egg cells.

Table 1 shows percent germination of seed obtained from the various crosses attempted during 1968 and 1969. Several important incidents occurred that reduced production of putative hybrid seed between fourwing saltbush and shadscale saltbush, mat saltbush, and spineless hopsage. During 1967, heavy winds and rain detached many of the sacked branches, and failure to cover the treated branches with cloth sacks prior to seed maturation resulted in losses attributed to rodents, deer, and natural drop. A late spring frost in 1968 killed most of the fruit at several locations. A large number of seedlings were lost in a greenhouse because of excessive heat and dehydration during the winter of 1969-70.

*Figure 10.--From left to right, Castle Valley clover saltbush (*Atriplex cuneata*), Castle Valley clover saltbush × fourwing saltbush hybrid, fourwing saltbush.*

*Figure 11.--Putative hybrid between fourwing saltbush and shadscale saltbush (*Atriplex confertifolia*).*

*Figure 12.--Artificial hybrid between fourwing saltbush and Gardner saltbush (*Atriplex gardneri*).*

Table 1.--[illegible] hopsage (Grbr)

Maternal (seeds) plants	Paternal (pollen) plants	Total branches treated	Branches bearing viable seed	[illegible] collected	Seed [illegible]	Percent [illegible]
Atca	Cela	11	2	24	[illegible]	12.5
Atca	Atco	6	[illegible]	177	[illegible]	[illegible]
Atca	Atco[2]	6	1	[illegible]	[illegible]	[illegible]
Atca	Save	10	1	[illegible]	[illegible]	[illegible]
Atca	Atca	12	[illegible]	[illegible]	15	[illegible]
Atca	Grbr	8	1	[illegible]	95	[illegible]
Atca	Atca	5	4	[illegible]	[illegible]	[illegible]
Atca	Control	12	[illegible]	[illegible]	[illegible]	[illegible]

*Species symbols from Plummer and others 1966b.

Perhaps the most common natural hybrids involving fourwing saltbush are *A.* [illegible] x *A. confertifolia* and *A.* [illegible]. The *canescens* x *confertifolia* hybrid closely resembles shadscale in general stature and habit. Spines on the hybrid are more slender, weaker, and much more branched than on the associated shadscale plant (fig. 11).

This hybrid is similar to fourwing saltbush in the possession of pedicellate bracts and slender branchlets, but it is intermediate between its parents in fruiting bracts, spines, and foliage. For example, the lower half of the bracts is like fourwing saltbush in the possession of four lateral wings, whereas, the upper portion has an expanded, foliaceous terminal tooth like shadscale (fig. 7). The *A. canescens* x *A. cuneata* combinations are highly variable. Several populations suggest local introgression. Individual plants combine parental characteristics in diverse ways.

Fourwing saltbush has a basic chromosome number of x = 9. Except for the diploid ($2n$ = 18) giant form in the sand dunes of the Little Sahara Recreation Area, Juab County, Utah, this species appears to be uniformly tetraploid ($2n$ = 36) (Stutz and others 1975).

Distribution and habitat: Fourwing saltbush is one of the most widespread and adaptable of western shrubs. It grows in a variety of soil types from the Great Plains to the coast ranges and from Canada to Mexico at elevations from below sea level to about 2,440 meters (8,000 feet). This species is most suited to deep, well drained mesas, ridges, slopes, sandy soil, sand dunes, and gravelly washes; but, vigorous plants have been found in heavy clays as well (Plummer and others 1966a) (fig. 13). Fourwing saltbush is frequently found intermixed with black greasewood, shadscale saltbush, basin big sagebrush (*Artemisia tridentata* subsp. *tridentata*), and occasionally black sagebrush (*A. nova*). Hanson (1962) noted that it tolerates a [illegible] soluble salt content of about 1,300 p/m. However, we believe there is considerable variation in salt tolerance among ecotypes of *A. canescens*.

Figure 13.--Fourwing saltbush as dominant vegetation, Desert Range Experiment Station, Millard County, Utah.

Ecotypes of this species exhibit great variation in their natural growth habit. As a result, many subspecies have been unjustifiably proposed. Plummer and others (1966a) have pointed out that a particular form usually is found in a given area, but that large variations may occur from bush to bush. For example, dwarf or short forms less than 1 meter in height are commonly found in desert or highly alkaline areas (fig. 14), whereas, forms that may reach 2 meters are usually observed in the higher foothills of the juniper-pinyon type (fig. 8). In the Little Sahara sand dunes of west-central Utah, a giant form to 4 meters in height occurs (fig. 15). These different ecotypes maintain the basic form of their parent stock when brought together on the same site (Plummer and others 1966a; Stutz and others 1975); so differences are genetically controlled.

Use: Fourwing saltbush is one of the most valuable forage shrubs in arid rangelands because of its abundance, accessibility, palatability, size, evergreen habit, nutritive value, rate of growth, and large volume of foliage. Its leaves, stems, and utricles provide browse in all seasons. In addition to providing forage and cover, this species is one of the most important shrubs for use in rehabilitation of depleted rangelands and in soil stabilization projects in western desert areas (Plummer and others 1968). Fourwing saltbush may be propagated easily by direct seeding, by transplants, and by stem cuttings.

Unfortunately, this species is a secondary or faculative selenium absorber and thus may be mildly poisonous where selenium occurs in the soil (Kingsbury 1964; Davis 1972). Losses have occurred when livestock have little or nothing else to eat (Hitchcock and others 1964).

Sampson and Jespersen (1963) gave fourwing saltbush a browse rating of good to fair for sheep, goats, and deer; and fair to poor for cattle and horses.

Atriplex confertifolia

Atriplex confertifolia (shadscale saltbush)

Shadscale saltbush is a compact spinescent shrub growing typically in dense clumps from 2 to 8 dm high and 3 to 17 dm wide (fig. 16). The rigid, brittle branches are scurfy when young, but become smooth and spiny with age.

The leaves are nearly circular to elliptic, oval, or oblong, 9 to 25 mm long, 4 to 20 mm wide. They are gray-scurfy especially at maturity.

Flowers of shadscale are similar to those of fourwing saltbush except in the nature of the bracts enclosing the seed. The bracts of shadscale are foliose, 5 to 12 mm long, broadly oval to almost round, united at the base, and have entire, free, somewhat spreading margins (fig. 7).

Shadscale blooms from late March in the southern portion of its range to mid-June in the northern portion (Hanson 1962). Utricles mature about 15 weeks after blooming. They tend to be fairly persistent through the winter months and are sought out by all grazing animals. Cleaned utricles of this species average 64,920 per pound (142/g) (Plummer and others 1968).

Hybridization: Hanson (1962) stated that shadscale hybridizes with Castle Valley clover saltbush (*Atriplex cuneata*) (fig. 17), fourwing saltbush, Garrett saltbush (*A. garrettii*), mat saltbush (*A. corrugata*), Gardner saltbush (*A. gardneri*), and possibly desertholly saltbush (*A. hymenelytra*). Hanson (1962) further states that natural hybrids with mat saltbush are nearly sterile and those with fourwing saltbush are completely sterile.

Hanson (1962) found a number of [illegible] along roadsides. He examined 420 saltbushes growing along a road at a station near Price, Utah. Of these, 215 (51 percent) were shadscale, 170 (44 percent) were mat saltbush, 28 (7 percent) were cuneate saltbush, and 7 (1.7 percent) were hybrids between shadscale saltbush and mat saltbush. The hybrids grew only a short distance from the pavement and all were under 3 years of age, having grown since road margins were last graded. None of the hybrids were found in adjacent stabilized vegetation. We have observed putative hybrids along Utah Highway 10, south of Emery, Utah.

The shadscale-mat saltbush hybrid is a woody shrub with decumbent to ascending branches. The branches do not root when in contact with the soil; and when mature, they form weak to strong unbranched spines. The bark is gray, soft, and spongy. The pale gray-green, densely scurfy, evergreen leaves measure 7 to 20 mm long, 4 to 9 mm wide, and are oblanceolate to elliptical or spatulate. The fruiting bracts are 8 to 10 mm long and 5 to 8 mm wide with fewer than eight tubercules scattered about the base or with tubercules absent. The bracts are united for about one-half of their length (fig. 7). This hybrid is nearly sterile. Out of 500 large utricles from the Price station, Hanson (1962) found only two with seeds.

Hanson (1962) found a single hybrid of *A. confertifolia* × *A. gardneri* growing intermixed with its probable parents along U.S. Highway 30 south, 3.3 km (2 miles) east of Ft. Bridger, Wyoming. According to him, the hybrid was a low shrub similar in general aspect to Gardner saltbush. However, it has a mass of spinose, unbranched, ascending twigs, and large bracts 8 mm long and 4 mm wide. These features are more like those of shadscale.

Sarcobatus vermiculatus

Filled utricles have been produced artificially when shadscale pollen was used to fertilize pistillate plants of fourwing saltbush. Of the seeds produced by this procedure, 7.9 percent were viable (table 1). We hope to produce fertile hybrids between these two species.

Plummer and others (1957) reported a number of natural hybrids between shadscale saltbush and cuneate saltbush in the Colorado River drainage 16 km (10 miles) south of Emery, Utah, on Utah Highway 10. Apparently, this is a fairly common hybrid in nature and should not be difficult to produce artificially.

H. C. Stutz and C. L. Pope (personal communication) of the Botany and Range Science Department of Brigham Young University have recently found shadscale occurs as a polyploid series from diploid ($2n$ = 18) to decaploid ($2n$ = 90).

Distribution and habitat: Shadscale occurs most often on heavier soils, although it has been found on soil containing as much as 70 percent sand. Soluble salts in these soils vary from 160 to 3,000 p/m and pH from 7.4 to 10.3 (Hanson 1962).

Shadscale is the dominant plant on over 129,000 km^2 (50,000 mi^2) from Canada to Mexico at elevations from 460 to 2,135 meters (1,500 to 7,000 feet) (Hanson 1962; Branson 1966). It can be found in nearly pure stands on alkaline soils in the Great Basin and other parts of the West (Benson and Darrow 1944). Over much of its range, shadscale occurs in mixed stands with species of greasewood (*Sarcobatus*) (fig. 18), sagebrush (*Artemisia*), hopsage (*Grayia*), rabbitbrush (*Chrysothamnus*), horsebrush (*Tetradymia*), and juniper (*Juniperus*). It endures highly alkaline soils better than most of these associates and can be found growing with such halophytes as glasswort (*Salicornia*) (Hall and Clements 1923). Bud sagebrush (*Artemisia spinescens*) is a

frequent codominant or [illegible] together. Numerous ecotypes of shadscale enable it to grow over a wide range of sites.

Use: Shadscale, in contrast to fourwing saltbush, becomes rigid and spiny as it matures, and during the winter some forms become nearly leafless. However, persistence of leaves varies greatly among areas of occurrence. The spiny characteristic saves this species from heavier grazing than it would otherwise receive and is believed to be a factor in its survival. Shadscale, nevertheless, is palatable to all classes of livestock; the seeds are the most preferred and nutritious part of the plant (U.S. Forest Service 1937). According to Sampson and Jespersen (1963), as the leaves and fruits drop in the autumn, they often accumulate around the parent shrubs. Livestock readily seek this accumulation. Sampson and Jespersen (1963) gave shadscale a browse rating of good to fair for sheep, goats, and deer; fair for cattle; and poor to useless for horses. Hutchings (1952) recorded heavy local damage to productive shadscale range by a snout moth (Pyralidae). The moth damage cleared the way for invasion of noxious halogeton (*Halogeton glomeratus*).

Since shadscale is generally more salt tolerant than fourwing, it apparently could be used for restoration of and soil stabilization on salt-bearing ranges. However, most trials have shown the species to be difficult to establish from direct seeding. It does establish well from transplanting in the early spring when soil moisture remains high for at least 6 weeks. Paradoxically, over a period of years, it shows good natural reproduction. Evidently, a seed source builds up in the ground to sprout and become established during favorable springs.

Atriplex corrugata (mat saltbush)

Mat saltbush is a low shrub that forms dense, extremely prostrate, nearly [illegible] mats 5 to 20 times wider than they are high (fig. 19). The prostrate branches often produce adventitious roots where they contact the soil. The bark is soft, spongy, and [illegible].

[illegible]

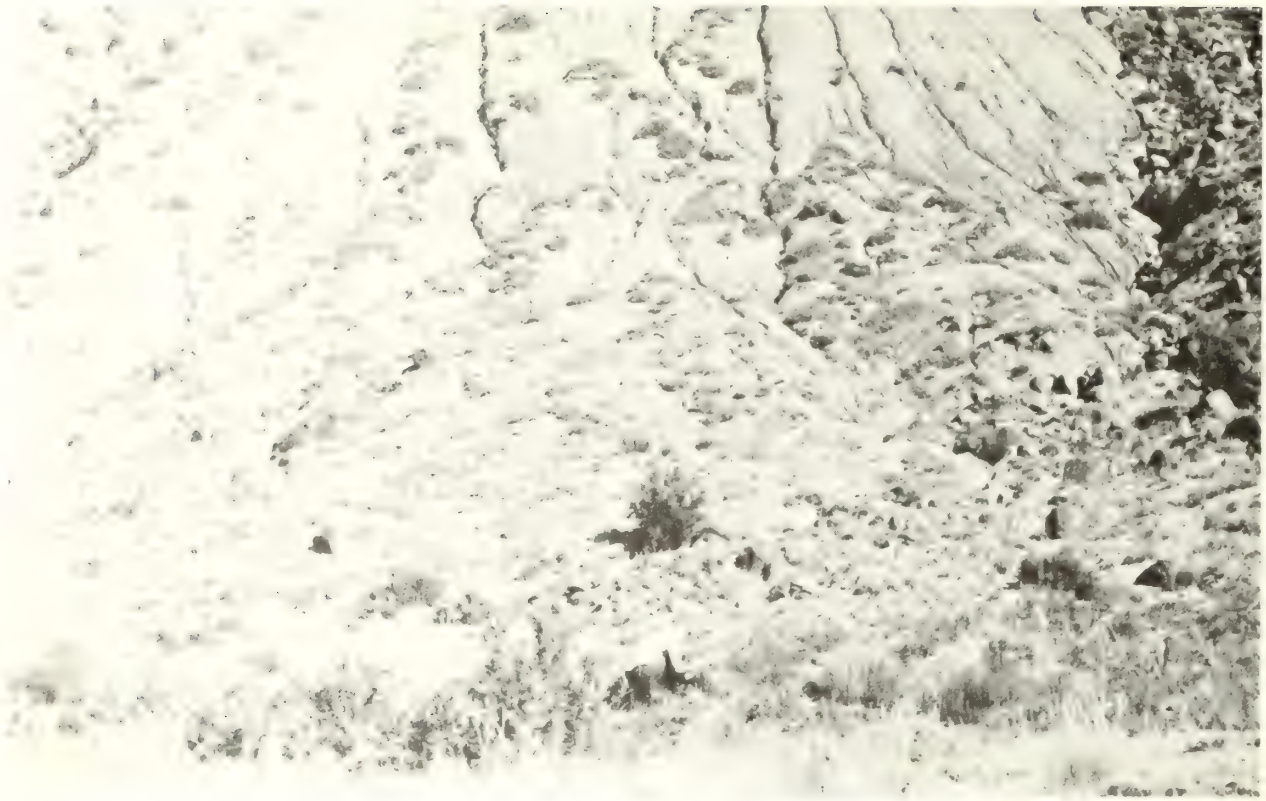


Figure 20.--Mat saltbush and Castle Valley clover saltbush growing on outcropping of Mancos shale in a juniper-pinyon-grass type in northeastern Sevier County, Utah.

The evergreen sessile leaves are opposite on the lower parts of the stems and alternate above. The blades are densely scurfy and measure 7 to 18 mm wide.

Bushes are dioecious or rarely monoecious. The yellow to light-brown staminate flowers are borne in glomerules 3 to 6 mm wide on nearly naked spikes. The pairs of fruiting bracts that enclose the pistils of the female flowers are sessile or subsessile, 3 to 5 mm long, 4 to 6 mm wide, united along seven-tenths of their length and usually densely tuberculate on the lower one-third (fig. 7).

Mat saltbush flowers from April to June and the fruit ripens 5 to 6 weeks later. There are about 100,900 cleaned utricles of mat saltbush per pound (223/g).

Hybridization: Viable seed has been obtained by artificially pollinating fourwing saltbush with pollen from mat saltbush (table 1). Natural hybrids between this species and *A. gardneri* and *A. confertifolia* have been found (Hanson 1962). Mat saltbush is tetraploid ($2n = 36$) (H. C. Stutz and C. L. Pope, personal communication).

Distribution and habitat: Mat saltbush is distributed mainly on soils derived from the Mancos Shale Formation in eastern Utah (fig. 20), western Colorado, and northwestern New Mexico at elevations from 1,220 to 2,130 meters (4,000 to 7,000 feet). It tolerates up to 13,000 p/m soluble salts and is often the only perennial plant present where such high concentrations of salt occur (Hanson 1962). Mat saltbush is probably the most halophytic shrub in the genus, but it is frequently found in areas where the salt concentration is not so high. In these areas, it may be associated with shrubs such as winterfat, cuneate saltbush, shadscale saltbush, fourwing saltbush, black greasewood, bud sagebrush, and gray molly (*Kochia americana* subsp. *vestita*). We have successfully transplanted young plants into a former greasewood type in the Great Basin.

Atriplex cuneata (Castle Valley clover saltbush)

Castle Valley clover saltbush is a low shrub with a more or less prostrate, woody, much-branched base and erect branches (fig. 21). The light gray-green, spatulate to broadly elliptic [illegible] (Clements 1923).

This species is usually dioecious. Its yellow to brown staminate flowers are borne in glomerules arranged in panicles. The pistillate flowers are borne in axillary clusters and consist of pistils enclosed by wingless bracts. At maturity, the bracts are 5 to 9 mm wide, irregularly toothed along their margins, and have numerous, flattened, crestlike tubercles on their sides (fig. 7 and 22).

Blooming occurs from mid-April to July, depending on elevation and on climatic conditions. Ripening of the fruit follows about 7 weeks later (Hanson 1962). There are about 81,660 cleaned, hammer-milled utricles of *A. cuneata* per pound (180/g).

[illegible] that hybridizes with every perennial *Atriplex* it is sympatric with except [illegible]. Included are [illegible] *garrettii*, *A. tridentata*, and *A. wolfii*. *Atriplex cuneata* has both diploid ($2n = 18$) and tetraploid ($2n = 36$) populations (H. C. Stutz and C. L. Pope, personal communication

[illegible]

Distribution and habitat: *Atriplex cuneata* occurs in highly alkaline soils in eastern Utah, southwestern Colorado, and northern New Mexico. In these areas, the species is often the dominant plant (fig. 23) or is codominant with *A. confertifolia* and *A. corrugata* (fig. 20).

Use: Castle Valley clover saltbush remains green and succulent throughout the winter and is highly palatable to all grazing animals. It is thus an important forage shrub in the highly alkaline areas where it occurs.

This shrub shows promise for use in artificial restoration of certain game winter ranges with highly saline-alkaline soil (McArthur and others 1974).

Atriplex gardneri (Gardner saltbush)

Gardner saltbush is a low subshrub. The lower one-fourth to three-fourths of the plant is slightly woody and the rest is herbaceous (fig. 24). Its habit varies from decumbent creeping forms to rounded forms 3 to 5 times broader than they are high. The spineless decumbent branches usually produce adventitious roots where they contact the soil. These plants also root sprout vigorously (Nord and others 1969). Annual flowering stems arise from the woody portion of the plant.

The lightly scurfy leaves are evergreen, spatulate to oblanceolate to obovate, 15 to 55 mm long, and 5 to 12 mm wide (Hanson 1962).

The majority of plants of this species are dioecious. The brown staminate flowers are borne in glomerules 3 to 5 mm wide on nearly naked one-branched terminal panicles (fig. 25). The pistillate flowers are borne on leafy spikes (fig. 26). Hanson (1962) observed that about 5 percent of the plants he inspected were monoecious.

burned 3 years before. Note its spreading habit from root sprouts.

Figure 26.--Pistillate Gardner saltbush showing developing utricles.

Fruiting bracts that enclose the female flower are [illegible] wide, and are sessile. Their surfaces range from smooth and free of tubercles to densely tuberculate. The apex of the bracts ends in an oval terminal tooth subtended by two slightly smaller lateral teeth (fig. 7).

Gardner saltbush flowers from mid-May to the first of July and intermittently following heavy rains.

The fruit ripens about 7 weeks after flowering. Cleaned utricles average 111,450 per pound (246/g) for this species (Plummer and others 1968).

Gardner saltbush was considered as a subspecies of Nuttall saltbush (*A. nuttallii*) by Hall and Clements (1923) in their classic monograph. They recognized six subspecies of Nuttall saltbush: [illegible], and *falcata*. They contended that "the first three subspecies form a very close group, and since they occupy the same region, it is questionable if all should not be treated as one." More recently, Hanson (1962, 1973) elevated the subspecies to specific rank. The taxonomy of this group remains somewhat confused. The species *tridentata* and *gardneri* are similar morphologically, but the former is usually hexaploid ($2n = 54$) and the latter tetraploid ($2n = 36$) (Bassett and Crompton 1971; H. C. Stutz and C. L. Pope, personal communication). *Atriplex tridentata* has been described as a subspecies of *A. gardneri* (Holmgren and Reveal 1966). We classify questionable collection as *A. gardneri*.

Nuttall saltbush (*A. nuttallii*), which is widespread in Wyoming, Montana, and Idaho, but only sparsely present in Utah, resembles Gardner saltbush in most characteristics. However, it root sprouts less vigorously than Gardner saltbush and it has the ability to aggressively stem layer (Nord and others 1969).

Hybridization: Fifty percent of the branches of pistillate fourwing saltbushes treated with Gardner saltbush pollen produced viable seed. This percentage was higher than that for any other treatment except *A. canescens* crossed with *A. canescens* where four out of five branches (80 percent) produced viable seed (table 1). Natural hybridization between Gardner saltbush and *A. confertifolia* also occurs. Gardner saltbush is tetraploid ($2n = 36$) (H. C. Stutz and C. L. Pope, personal communication).

Distribution and habitat: Gardner saltbush is much more restricted in its habitat than fourwing saltbush and shadscale. It is most abundant on nearly bare badland clay soils, which contain to 5,500 p/m soluble salts (fig. 27) (Hanson 1962). It occurs in Wyoming, Colorado, Utah, and southern Idaho.

Use: Gardner saltbush is important as cover on arid sites and as browse for big game and livestock. It is being tested with an assortment of fire resistant shrubs for use in reducing fire hazard in southern California. Such shrubs are being used to replace the highly flammable, high-volume chaparral plants presently there (Nord and others 1969).

Atriplex obovata (broadscale saltbush)

Broadscale saltbush is a subshrub to 8 dm in height with a woody, spreading base that produces numerous ascending to erect branches (fig. 28). The silvery, scurfy, deciduous leaves are elliptical to obovate, 1 to 3.5 cm long, 1 to 2 cm wide, with a short petiole.

This species has yellow staminate flowers borne in small glomerules and arranged 500 to 5,000 to a panicle. The fruiting bracts are broadly cuneate or obovate, 4 to 5 mm long, 5 to 9 mm broad, with smooth or sometimes slightly tubercled surfaces (fig. [illegible]

Figure 27.—Common saltbush growing in western Juniper Valley, Tooele County, Utah.

28.--*Broadscale saltbush* (Atriplex obovata) *growing in the Hamblin Wash drainage of Tuba City, Coconino County, Arizona.*

ound (458/g).

Hybridization: Hanson (1962) reported there are no definitely known hybrids etween *A. obovata* and other species; however, *Atriplex* specimens intermediate between . . have been reported from . . (1961). . C. Stutz and C. L. Pope (personal communication) have discovered both diploid 2n = 18) and tetraploid (2n = 36) .

Distribution and habitat: Broadscale saltbush ranges from southeastern Utah, eastrn Arizona, through western New Mexico and western Texas, to northern Mexico. The argest individual plants of this species are found in the more sandy localities. Broadcale saltbush tolerates salinity from 165 to 4,900 p/m soluble salts (Hanson 1962). It s commonly associated with such halophytes as black greasewood, seepweed (*Suaeda*), and lkali sacaton (*Sporobolus airoides*).

Use: Broadscale saltbush is an important browse plant in alkaline areas. It makes apid growth and is most succulent in the spring. Within areas of adaptation, this pecies should be useful for stabilizing disturbed sites. It has been observed to inade the disturbed margins of newly constructed highways.

Ceratoides lanata (winterfat)

Winterfat's longstanding scientific binomial, , has been recently hanged by Rewell (1971). He proposed the name . Winterfat is an rect or spreading subshrub that shows wide variation in stature from dwarf forms less han 40 cm in height to larger forms to 1.5 meters (fig. 29). The dwarf forms are

Figure 29.--
(*Ceratoides lanata*
).

herbaceous above a woody base. Taller forms tend to be woody throughout (fig. 30). Branches and leaves are covered with a dense coating of stellate and simple hairs that are white when young, but become rust colored with age.

The leaves are alternate, linear, 5 to 50 mm long, with entire, strongly revolute margins.

Winterfat may be either monoecious or dioecious. The flowers are borne in dense paniculate clusters along the upper portion of the branches. The pistillate flowers are below the staminate flowers on monoecious plants.

Staminate flowers lack bracts and petals. They are comprised of four sepals and four stamens borne opposite the sepals.

Pistillate flowers lack both sepals and petals. Pistils are enclosed by a pair of bracts that are united more than half their length. The bracts are covered and often obscured by long, silky hairs (fig. 31). These long hairs distinguish winterfat from species of *Atriplex*.

Site and climate permitting, winterfat blooms between May and August. The fruit ripens from September to November and is dispersed by wind in late fall and winter. Seed production is extremely variable. A scant crop is produced in most years. However, a heavy seed crop can be produced in years of good summer storms coupled with the absence of summer grazing. Such productive crops on dry desert ranges may occur but once in a decade. Cleaned seeds of this shrub average 112,275 per pound (248/g) (Plummer and others 1968).

Figure 30.--Mature tall form of winterfat with good seed production, growing on Shay Mesa, northeast of Monticello, San Juan County, Utah.

Figure 41.--[illegible]

Winterfat is remarkably resistant to drought, and even on dry sites will produce seed in the third and fourth year. On favorable sites, plants have produced some seed in their first year of growth. The species has a deep taproot and numerous extensive lateral roots. The plant may appear dead after unusually dry years, but it normally recovers after rain. It exhibits strong reproductive qualities; however, establishment from artificial seeding has often been unsuccessful because seedlings are highly sensitive to frost damage.

Hybridization: The different ecotypes (forms) of winterfat not only show wide variation in stature, but also in seed production, seed size, seedling germination and vigor, pubescence on fruit and seed, and tolerance to varying pH in soils.

A more woody, somewhat spinescent form of winterfat (*C. lanata* ssp. *subspinosa*) occurs on rocky hills in southern Utah, Arizona, California, and Mexico. It apparently is the only form present in southern Arizona. This subspecies shows intergradation in all characteristics with typical winterfat (Kearney and Peebles 1960). Possible production of superior strains through hybridization and selection appears excellent because of the wide variation between ecotypes and the natural hybridization with subspecies *subspinosa*. Riedl and others (1964) found that parts of female plants covered with muslin bags did not set seed, but uncovered parts did; so winterfat appears to be wind pollinated. Thus, one should be able to bag a branch bearing pistillate flower buds for use in hybridization. The desired pollen could be introduced when the flowers are in bloom and the stigmas receptive. A limited number of viable seeds have been obtained by pollinating fourwing saltbush pistillate flowers with winterfat pollen (table 1). None of the seedlings have survived. Winterfat is diploid with a chromosome number of $2n = 18$ (Bassett and Crompton 1971).

Distribution and habitat: Winterfat is most abundant on lower foothills, plains, and valleys with dry subalkaline soils in Utah, Nevada, Arizona, and New Mexico. In the Great Basin, it often occurs in pure stands over thousands of hectares (Benson and Darrow 1944), and is an important component over millions of hectares of the salt desert shrub type (fig. 32). Winterfat ranges from Canada through the Great Basin and Rocky Mountain States to Mexico, and from California and Washington eastward to Texas and North Dakota (Branson 1966). It also grows over a wide range of altitudes. In Utah, it occurs from the lower Sonoran zone to the Alpine ridges. Dwarf forms usually occur on desert floors, on areas of high salt concentration, and on high mountain tops. The larger forms occur on alluvial fans, foothills, and mesas on ponderosa pine and juniper-pinyon sites.

Use: Winterfat is a superior nutritious winter browse for livestock and big game. Sheep, cattle, antelope, elk, deer, and even rabbits utilize it (fig. 33). Except for the woody base and larger stems, the plant is edible. Overgrazing has greatly reduced and even eliminated winterfat on some areas, even though it is relatively tolerant to grazing. Winterfat is potentially one of the most useful shrubs for planting to increase cover and forage on alkaline soils of desert ranges in Utah and adjacent States where the average annual precipitation is less than 25 cm (10 inches). Sampson and Jespersen (1963) give winterfat a browse rating of excellent to good for cattle and sheep; excellent to fair for goats; good to fair for deer; and fair for horses.

The species is a good natural increaser and should be highly useful for stabilization in areas where it naturally occurs. Good stands have resulted from broadcasting utricles on such areas.

Figure 32.--Pure stand of winterfat on a fine silty soil at Desert Range Experiment Station, Millard County, Utah.

Grayia—Common Floral Characteristics

Grayia, like *Atriplex*, has staminate flowers of four or five sepals, four or five stamens, and pistillate flowers that lack both sepals and petals but have pistils enclosed by pairs of bracts. The margins of each pair of bracts are united from base to apex except for a minute apical opening. Collotzi (1966) on the basis of a morphological, embryological, and chromatographic study recommended that *Grayia* be reclassified as *Atriplex*. From our observations, we believe this would be appropriate; but, because of the long past usage, we suggest that the present nomenclature remain unchanged.

Grayia brandegei (spineless hopsage)

Spineless hopsage is a subshrub to 1 meter tall (fig. 34) with linear-oblanceolate to obovate leaf blades 1.5 to 4.5 cm long (Collotzi 1966).

The flowering period varies between mid-June and mid-August. Seed matures in late September through early October. Utricles (fig. 35) persist on the plants until January and some may last through the winter. These are often removed by small mammals and birds. Cleaned seeds of *Grayia brandegei* average 189,950 per pound (419/g)(Plummer and others 1968).

Hybridization: Drobnick and Plummer (1966) reported occurrence of natural hybrids of spineless hopsage with shadscale saltbush and cuneate saltbush. Viable seeds have been obtained by artificially pollinating fourwing saltbush pistillate flowers with pollen from spineless hopsage. This cross of all those attempted on fourwing saltbush yielded the highest percentage of viable seed; however, of the eight branches treated,

Figure 34.--[illegible] growing in foothills in northwestern Antelope Valley, Sanpete County, Utah.

Figure 35.--Pistillate spineless hopsage with developing utricles.

nly one produced viable seed (table 1). Unfortunately, none of the resultant seedlings urvived. These progeny are essential for verifying the nature of the purported crosses. e are confident that our continuing hybridization work, associated with better care of ny resultant seedlings, will yield the needed progeny. Spineless hopsage is tetraploid ith a chromosome number of $2n = 36$ (C. L. Pope and E. D. McArthur, data on file at hrub Sciences Laboratory, Provo, Utah).

Distribution and habitat: Spineless hopsage is generally restricted to shale ormations of the Upper Colorado River Drainage. It favors silty clay loam soil erived from shales. Collotzi (1966) noted it occurred under mildly alkaline (pH 7.4 o 7.7) conditions. Other populations occur on similar soils in central Utah (fig. 36) nd in southeastern Colorado.

Use: This species may be used as browse by livestock and big game. It germinates nd produces seedlings readily; but, unless protected, these are quickly taken by odents and rabbits. These small mammals have shown a high preference for the seedlings stablished at several locations. Kingsbury (1964) lists spineless hopsage as a ossible secondary or facultative selenium absorber. As such, it could be mildly oisonous in areas where the soil contains selenium.

Grayia spinosa (spiny hopsage)

Spiny hopsage is an erect, diffusely branched, spinescent shrub from 3 to 12 dm in eight (fig. 37). It differs in many respects from spineless hopsage, but both species ave similar utricles (fig. 7, 35, 38).

Figure 37.--Spiny hopsage (Grayia spinosa) *growing on a restricted type of heavy, white calcareous soil on top of foothills south of Ephraim, Sanpete County, Utah.*

Figure 38.--Closeup of spiny hopsage showing developing utricles on branch tips and the fleshy, oblanceolate leaves.

The deciduous leaves are oblanceolate, [illegible], and mewhat fleshy (fig. 38).

The small, greenish unisexual flowers usually occur on separate plants, but in me populations as many as 5 percent of the shrubs are monoecious. The staminate owers are clustered in glomerules in the axils of leaves, whereas the pistillate owers are mostly in dense terminal spikes.

The fruits are enclosed by pairs of conspicuous, rounded or obovate, flat-winged, ssile bracts, 5 to 12 mm wide, and often tinged with red (fig. 7) (McMinn 1939).

The flowering period of spiny hopsage is from April to June. On a site in central ah, south of Ephraim, at an elevation of 1,830 meters (6,000 feet), seeds matured om June 15 to July 17 over a 5-year period. In most places, the seeds tend to be ture and disseminating before July 15. Shortly after seed maturity, the leaves ordi- rily fall, but there is wide variation in this characteristic. An unusual form in ggett County, northeastern Utah, has some leaves remaining on the shrub throughout e following season. Cleaned seeds (seeds removed from the utricles) of this shrub erage 166,765 per pound (368/g) (Plummer and others 1968).

Hybridization: Hybrids between fourwing saltbush and spiny hopsage have been tained by treating pistillate flowers of fourwing saltbush with pollen from spiny psage (Drobnick and Plummer 1966). Spiny hopsage has a chromosome number of $2n = 36$. L. Pope and E. D. McArthur, data on file at the Shrub Sciences Laboratory, Provo, ah).

Distribution and Habitat: Spiny hopsage is found over a wide range of soils on ains and foothills in California northward to eastern Oregon and Washington, and east New Mexico, Colorado, and Wyoming. Soils are typically high in calcium and strongly sic but, in some areas, they are essentially neutral. On extensive tracts, spiny psage occurs with big sagebrush. It is somewhat fire tolerant, often surviving fires at kill sagebrush.

Use: Spiny hopsage is a valuable forage plant in areas where it is abundant, rticularly in the spring when it is in full leaf. This is the time when livestock d game seek it out. This species was given a browse rating by Sampson and Jespersen 963) of good to fair for sheep, goats, and deer; fair to poor for cattle; and poor useless for horses.

Kochia americana subsp. *vestita* (gray molly summer cypress)

Gray molly summer cypress is a small, woody-based subshrub to 5 dm tall (fig. 39). s numerous, annual, erect branches and leaves are covered with long, silky hairs. e linear, fleshy, more or less terete leaves are 5 to 30 mm long. Hairy perfect or stillate flowers are borne singly or in small clusters in the axils of leaves along most the full length of the branches. At anthesis, the hooded calyx lobes are about 5 mm long and closely cover the ovary. At maturity, the fruit is largely concealed the persistent calyx, which develops conspicuous, horizontal, fanlike papery wings 3 mm long. This species blooms from June to August. It produces about 257,200 eaned seeds per pound (566/g).

Hybridization: Natural hybrids between *Kochia americana* and other native species e unknown. Perhaps improvement of this species by hybridization with introduced ecies such as *Kochia prostrata* will prove feasible. This is yet to be tested. The romosome number of gray molly is unknown.

Kochia americana ssp. vestita habit.

Distribution and Habitat: Gray molly usually occurs in saline or alkaline clay soil on plains and foothills between 1,370 to 1,830 meters (4,500 to 6,000 feet). Its range extends from southern Montana west to Oregon and south to New Mexico, Arizona and California.

Use: Kochia americana is quite widely used as winter forage by sheep when it is sufficiently abundant (Kearney and Peebles 1960). Sampson and Jespersen (1963) gave this species a browse rating of fair to poor for sheep and goats; poor to useless for deer; and useless for cattle and horses. In Utah, we have observed that *K. americana* ssp. *vestita* may be closely grazed by sheep and cattle on winter ranges.

Gray molly appears to have usefulness in revegetation of areas with a high salt concentration, particularly spent coal and oil shales. Trials are warranted on these kinds of sites but, as far as is known, have not been carried out.

Kochia prostrata (prostrate kochia)

Prostrate kochia is generally a long-lived, highly variable, woody-based subshrub However, some ecotypes may be definite upright shrubs. It ranges from less than 0.3 meter to over 1 meter in height (fig. 40). Ascending branches are covered with short to long woolly hairs. Leaves are flat, linear to filiform, and hairy. Flowers are borne in small clusters (glomerules) in the axils of slightly reduced leaves on the upper part of the stem. The perianth consists of a hairy, persistent calyx. As the fruit develops, the calyx forms dorsal appendages around it that are rounded, flat and tuberclelike, or oblong and winglike (Shishkin 1936). Blooming occurs from July to September. Seeds of prostrate kochia number approximately 500,000 per pound (1,102/g) (Keller and Bleak 1974).

*Figure 40.--Three-year-old prostrate kochia (*Kochia prostrata*) transplanted as seedling to a revegetated range southeast of Ephraim, Sanpete County, Utah. This plant began producing seed the first year as is common for this species. (The hat shows the relative size of the plant.)*

Hybridization: Prostrate kochia [illegible] geographic races and ecotypes (Shishkin [illegible] selection and development of superior [illegible] is diploid, 2n = ca.18 (C.L. Pope and [illegible] Laboratory, Provo, Utah).

Distribution and Habitat: Prostrate kochia is native to arid and semiarid regions of central Eurasia where it grows on alkaline, stony, and sandy steppes and plains (Shishkin 1936). Seed of several ecotypes were introduced into the United States during the 1960's. This species appears to adapt well to the climate and soils of the Intermountain area (Keller and Bleak 1974). It establishes readily from transplants (fig. 40) and seed (fig. 41).

Figure 41.--Rows of prostrate kochia planted for seed increase at the Snow Field Station, Sanpete County, Utah. Note the volunteer reproduction between rows.

Use: Prostrate kochia shows considerable potential for becoming a valuable fora and cover plant on our arid western ranges. In its native habitat, it is a drought-resistant, salt-tolerant species and is highly valued as a forage plant. Sheep, goat camels, and horses all use it (Shishkin 1936). Our preliminary observations in Utah indicate that this species is sought out by mule deer. Kochia readily establishes fr seed, grows rapidly and, under favorable conditions, reaches sexual maturity in 1 yea (McArthur and others 1974). Once established, it is a good natural spreader.

Sarcobatus vermiculatus (black greasewood)

Black greasewood is an erect, spiny-branched shrub to 3 m tall (fig. 42). Its numerous rigid branches become gray with age. The deciduous, bright-green leaves are 1 to 4 cm long, narrowly linear, and semiterete.

This shrub is usually monoecious with staminate flowers borne in catkinlike spik 0.5 to 3 cm long. These flowers lack both sepals and petals and consist only of two three stamens borne under closely packed, long-stalked, shieldlike bracts. The pistillate flowers are borne below the staminate catkin in the axils of reduced leaf-like bracts. These flowers have a closely compressed calyx barely 1 mm long at anthesis, which greatly enlarges in fruit. The flowers bloom from May to July.

The pistils are enclosed by cuplike perianths. The lower portion of each perian becomes adherent to the ovary and the upper portion expands into a broad, membranous, horizontal wing, 6 to 13 mm wide, in the fruit (fig. 7). Cleaned seeds of this speci average approximately 285,600 (630/g) cleaned seed per pound.

Hybridization: Drobnick and Plummer (1966) reported a small population of putat hybrid derivatives of fourwing saltbush and black greasewood growing among parental species on the east side of the Lakeside Mountains north of Delle, Tooele County, Uta

Figure 42.--Black greasewood (Sarcobatus vermiculatus) *growing near Tuba City, Coconino County, Arizona.*

Probnick and Plummer (1966) have [illegible] pistillate flowers with black greasewood [illegible] been planted in a test plot near Manti, Utah. In our tests, 1 out of 10 pistillate fourwing saltbush branches produced viable seed when cross-pollinated with black greasewood (table 1). Additional studies are needed to verify the true nature of these putative hybrids. Bassett and Crompton (1970) report black greasewood to be tetraploid with a chromosome number $n = 18$. Stutz and Pope (personal communication) have discovered both tetraploid [illegible] greasewood.

Distribution and Habitat: Black greasewood grows on a wide range of soils, but is most characteristic on rather heavy, alkaline soils where flood waters collect or on soil that have a high water table at least part of the year. Salts accumulate in such areas. Thus greasewood is usually associated with soils of high salt (alkali carbonates, or "black alkali") content (Shantz and Piemeisel 1940; Kearney and Peebles 1960).

Black greasewood is found at low and middle elevations from Alberta, Canada, south to Texas and California, and from the Dakotas, Colorado, and New Mexico west to Washington, Oregon, and California (Dayton 1931). A smaller species of greasewood, *S. baileyi*, occurs on desert hillsides and plains in association with shadscale saltbush, winterfat, and other salt desert shrubs in eastern California and western Nevada. This shrub seldom occurs in pure stands as does *S. vermiculatus*.

Black greasewood can be found in nearly pure stands in the more saline areas of its range. In less saline areas, it may be found growing with such shrubs as shadscale saltbush, Gardner saltbush, green rubber rabbitbrush (*Chrysothamnus nauseosus* ssp. *consimilus*), whiteflower, or alkali rabbitbrush (*C. albidus*), basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*) (fig. 45), bud sagebrush (*A. spinescens*), spiny hopsage (*Grayia spinosa*), and winterfat (*Ceratoides lanata*).

Fig. 45.--A mixed [illegible] Ephraim, Sanpete County, Utah.

Use: Black greasewood is used as browse by cattle and sheep. These animals eat the young shoots and leaves in winter and spring (Kearney and Peebles 1960). According to Kingsbury (1964), "greasewood is considered useful forage by most ranchers, and many large areas of range would be worthless for raising animals if it were absent."

Black greasewood was given a browse rating of fair to poor for sheep and goats; poor for deer; fair to useless for cattle; and useless for horses by Sampson and Jespersen 1963).

Unfortunately, black greasewood contains soluble oxalates, which may cause poisoning and death if hungry animals consume a large amount of greasewood in a short time. This can be prevented by providing other forage in the diet or at least by spreading out the consumption of greasewood over a period of several hours or more (Kingsbury 1964). In its distribution range, it shows marked ability to naturally establish on disturbed areas, such as roadsides.

APPENDIX

CHENOPODIACEAE—Key to Genera and Species

(Nomenclature follows Flora of the [illegible])

1a. Flowers perfect or polygamous.....*Kochia*

2a. Branches erect, not more than 0.5 meter high; leaves fleshy, linear, more or less terete...*K. americana* subsp. *vana*

2b. Branches ascending, up to 1.2 meter high; leaves not particularly fleshy, linear to filiform, flat.....*K. prostrata*

1b. Flowers imperfect, monoecious or dioecious.

3a. Shrubs spinescent; leaves narrowly linear, semiterete; staminate flowers without perianth, borne in catkinlike spikes; fruit with a horizontal wing.....*Sarcobatus vermiculatus*

3b. Shrubs or subshrubs, not spinescent, or if spinescent, then leaves different from above; staminate flowers with perianth, not borne in catkinlike spikes; fruits not with horizontal wings.

4a. Bracts of fruit with many long hairs that form the conspicuous feature of the inflorescence; margins of leaves rolled tightly downward (revolute); hairs on branches and leaves stellate...*Krascheninnikovia lanata*

4b. Bracts of fruit glabrous; margins of leaves not revolute; hairs not stellate..5

5a. Margins of fruiting bracts united from base to apex, the apical opening minute; pubescence of simple or branched hairs, rounded axillary buds present.....*Grayia*

6a. Shrubs with spinescent branches; fruiting bracts glabrous, not keeled, usually over 6 mm wide.....*G. spinosa*

6b. Shrubs not spinose; fruiting bracts scurfy, pubescent, keeled at maturity, usually less than 6 mm wide.....*G. brandegei*

5b. Margins of fruiting bracts only partially united or not united at all; pubescence of inflated hairs or lacking; rounded axillary buds lacking.....*Atriplex*

7a. Fruiting bracts normally with four lateral wings; shrubs to 2 meters or occasionally more high.....*A. canescens*

7b. Fruiting bracts without lateral wings; spinose shrubs or subshrubs normally less than 2 meters high.

8a. Shrub spinose; staminate flowers yellow; fruiting bracts foliose, united only at the base, with smooth surfaces and entire or nearly entire margins....*A. confertifolia*

8b. Subshrubs, weakly or not spinose; staminate flowers yellow or brown; fruiting bracts not foliose, at least one-third united, with surface frequently appendaged or margins toothed, sometimes both.....9

9a. Plants [illegible]
leaves [illegible]
tic; lower [illegible]
ing bract [illegible]
truncate, dentate apex and usually
smooth sides . . . . . .

9b. Plants more or less prostrate; lower leaves opposite or subopposite; leaves usually narrower than those of [illegible] fruiting bracts longer than broad, with sides usually appendaged.

10a. Plants prostrate mats under 15 cm; leaves less than 4 mm wide; staminate flower in spikes; fruiting bracts appendaged to the lower one-third. . . . . .

10b. Plants usually over 15 cm tall; leaves more than 4 mm wide; staminate flowers in panicles; fruiting bracts various.

11a. Fruiting bracts [illegible] mm wide, usually heavily tuberculate; leaves light gray-green. . . . . .

11b. Fruiting bracts 2 to 5 mm wide without tubercles, or if present, these less than 1 mm long; leaves [illegible]

PUBLICATIONS CITED

Bassett, I. J., and C. W. Crompton.
1970. *In*: Löve, A. IOPB chromosome number reports, XXVII. Taxon 19:437-442.

Bassett, I. J., and C. W. Crompton.
1971. *In*: Löve, A. IOPB chromosome number reports, XXXIV. Taxon 20:785-797.

Benson, L., and A. Darrow.
1944. A manual of southwestern desert trees and shrubs. Univ. Ariz. Biol. Bull. 6, 411 p.

Blauer, A. C., A. P. Plummer, E. D. McArthur, R. Stevens, and B. C. Giunta.
1975. Characteristics and hybridization of some important Intermountain shrubs. I. Rose family. USDA For. Serv. Res. Pap. INT-169, 36 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Branson, F. A.
1966. Geographic distribution and factors affecting the distribution of salt desert shrubs in the United States, p. 13-43. *In*: USDI Bur. Land Manage. Salt Desert Shru Symp., 292 p. Cedar City, Utah. August 1966.

Brown, G. D.
1956. Taxonomy of American *Atriplex*. Am. Midl. Nat. 55:199-210.

Collotzi, A. W.
1966. Investigations in the genus *Grayia*, based on chromatographic, morphological, and embryological criteria. M.S. thesis, Utah State Univ., 30 p.

Cook, C. W.
1972. Comparative nutritive value of forbs, grasses, and shrubs, p. 303-310. *In*: McKell, C. M., J. P. Blaisdell, and J. R. Goodin, eds., Wildland shrubs--their biology and utilization. USDA For. Serv. Gen. Tech. Rep. INT-1, 494 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Cook, C. W., L. A. Stoddart, and L. E. Harris.
1951. Measuring consumption and digestibility of winter range plants by sheep. J. Range Manage. 4:335-346.

Davis, A. M.
1972. Selenium accumulation in a collection of *Atriplex* species. Agron. J. 64:823-8

Dayton, W. A.
1931. Important western browse plants. U.S. Dep. Agric. Misc. Publ. 101, 214 p.

Drobnick, R., and A. P. Plummer.
1966. Progress in browse hybridization in Utah. Proc. Conf. West. State Game and Fish Comm. 46:203-211.

Esplin, A. C., J. E. Greaves, and L. A. Stoddart.
1937. A study of Utah's winter range: composition of forage plants and use of supple ments. Utah Agric. Exp. Stn. Bull. 277, 48 p.

Gates, G. H., L. A. Stoddart, and C. W. Cook.
1956. Soil as a factor influencing plant distribution of salt deserts of Utah. Ecol Monogr. 26:155-175.

Hall, H. M. and F. E. Clements.
1923. The phylogenetic method in taxonomy; the North American species of *Artemisia*, *Chrysothamnus*, and *Atriplex*. The Carnegie Inst. Wash. Publ. 326, 355 p.

Hanson, C. A.
1962. Perennial *Atriplex* of Utah and the northern deserts. M.S. thesis, Brigham Young Univ. 133 p.

Hanson, C. A.
1973. Perennial *Atriplex*, p. 80-81. *In*: Welsh, S. L., and G. Moore. Utah Plants: Tracheophyta. 474 p. Brigham Young Univ. Press, Provo, Utah.

Harrington, H. D.
1954. Manual of the plants of Colorado. 666 p.
Hitchcock, C. L., A. Cronquist, M. Ownbey, and J. W. Thompson.
1964. Vascular plants of the Pacific Northwest. Part 2: Saliceae to Saxifragaceae. 597 p. Univ. Wash. Press, Seattle.
Holmgren, A. H., and J. L. Reveal.
1966. Checklist of the vascular plants of the Intermountain region. Intermt. For. and Range Exp. Stn. Res. Pap. INT-32, 160 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
Howell, J. T.
1971. A new name for "Winter fat." Madroño 21:111.
Hutchings, S. S.
1952. Snout moth damage to shadscale in southern Idaho. Natl. Woolgrower 42:24-25, 44.
Kearney, T. H., and R. H. Peebles.
1960. Arizona flora. 2nd ed. 1032 p. Univ. Calif. Press, Berkeley and Los Angeles.
Keller, W., and A. T. Bleak.
1974. Kochia prostrata: a shrub for western ranges? Utah Sci. 35:21-25.
Kingsbury, J. M.
1964. Poisonous plants of the United States and Canada. 626 p. Prentice-Hall, Inc., Englewood Cliffs, N. J.
McArthur, E. D., B. C. Giunta, and A. P. Plummer.
1974. Shrubs for restoration of depleted ranges and disturbed areas. Utah Sci. 35:28-34.
McMinn, H. E.
1939. An illustrated manual of California Shrubs, 663 p. Univ. Calif. Press, Berkeley and Los Angeles.
McNulty, I.
1969. The effect of salt concentration on the growth and metabolism of a succulent halophyte, p. 255-262. *In*: Huff, C. and M. Riedesel, eds. Physiological systems in semiarid environments. Univ. N. M. Press, Albuquerque.
Moore, R. T., S. W. Breckle, and M. W. Caldwell.
1972. Mineral ion composition and osmotic relations of *Atriplex confertifolia* and *Eurotia lanata*. Oecologia (Berl.) 11:67-74.
Nord, E. C., D. R. Christensen, and A. P. Plummer.
1969. *Atriplex* species (or taxa) that spread by root sprouts, stem layers, and by seed. Ecology 50:524-526.
Plummer, A. P., D. R. Christensen, and S. B. Monsen.
1968. Restoring big-game ranges in Utah. Utah Div. Fish and Game Publ. 68-3, 183 p.
Plummer, A. P., R. L. Jensen, and H. D. Stapley.
1957. Job completion report for game forage revegetation project W-82-R-2. Utah State Dep. Fish and Game Inf. Bull., 1956-1957, 128 p.
Plummer, A. P., S. B. Monsen, and D. R. Christensen.
1966a. Fourwing saltbush, a shrub for future game ranges. Utah State Dep. Fish and Game Publ. 66-4, 12 p.
Plummer, A. P., S. B. Monsen, and D. R. Christensen.
1966b. Intermountain range and plant symbols, 69 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
Riedl, W. A., K. H. Asay, J. L. Nelson, and G. M. Telway.
1964. Studies of *Eurotia lanata* (winterfat). Wyo. Agric. Exp. Stn. Bull. 425, 17 p.
Sampson, A. W., and B. S. Jespersen.
1963. California range brushlands and browse plants. Calif. Agric. Exp. Stn. Ext. Serv. Man. 33, 162 p.
Shantz, H. L., and R. L. Piemeisel.
1940. Types of vegetation in Escalante Valley, Utah, as indicators of soil conditions. U.S. Dep. Agric. Tech. Bull 713, 32 p
Shishkin, B. K. (ed.).
1936. Flora of the USSR. Vol. 6:Centrospermae, 731 p. (Transl. from Russian, 1970. Israel Prog. for Sci. Transl. Ltd. IPST Cat. 5402).

Stutz, H. C., J. M. Melby, and G. K. Livingston.
1975. Evolutionary studies of *Atriplex*. A relic *Gigas* diploid population of *Atriple canescens*. Am. J. Bot. 62:236-245.
U.S. Department of Agriculture, Forest Service.
1937. Range plant handbook, 841 p. U.S. Gov. Print. Off., Washington, D.C.

ADDITIONAL PUBLICATIONS

Clausen, J., D. Keck, and W. M. Heisey.
1940. Experimental studies on the nature of species. Carnegie Inst. Wash. Publ. 520, 452 p.
Davis, R. J.
1952. Flora of Idaho, 828 p. Wm. C. Brown Co., Dubuque, Iowa.
Holmgren, A. H.
1974. Shrubs in Utah and the Intermountain region. Utah Sci. 35:3-4.
Springfield, H. W.
1970. Germination and establishment of fourwing saltbush in the southwest. USDA For Serv. Res. Pap. RM-55, 48 p. Rocky Mt. For. and Range Exp. Stn., Ft. Collins, Colo
Stebbins, G. L.
1959. The role of hybridization in evolution. Am. Philos. Soc. Proc. 103:231-251.
Tidestrom, I.
1925. Flora of Utah and Nevada. Contrib. from U.S. Natl. Herb. 25:1-665.
Tidestrom, I., and T. Kittell.
1941. A flora of Arizona and New Mexico. 897 p. Cathol. Univ. Am. Press, Washington, D.C.
U.S. Department of Agriculture, Forest Service.
1974. Seeds of woody plants in the United States. Agric. Handb. 450, 883 p., U.S. Gov. Print. Off., Washington, D.C.
Welsh, S. L., and G. Moore.
1973. Utah plants: Tracheophyta. 474 p. Brigham Young Univ. Press, Provo, Utah.

Blauer, A. Clyde, A. Perry Plummer, E. Durant McArthur, Richard Stevens, and Bruce C. Giunta

1975. Characteristics and hybridization of important Intermountain shrubs. II. Chenopod family. USDA For. Serv. Res. Pap. INT-177, 32 p., illus. Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.

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REVEGETATION OF ACID MINING WASTES IN CENTRAL IDAHO

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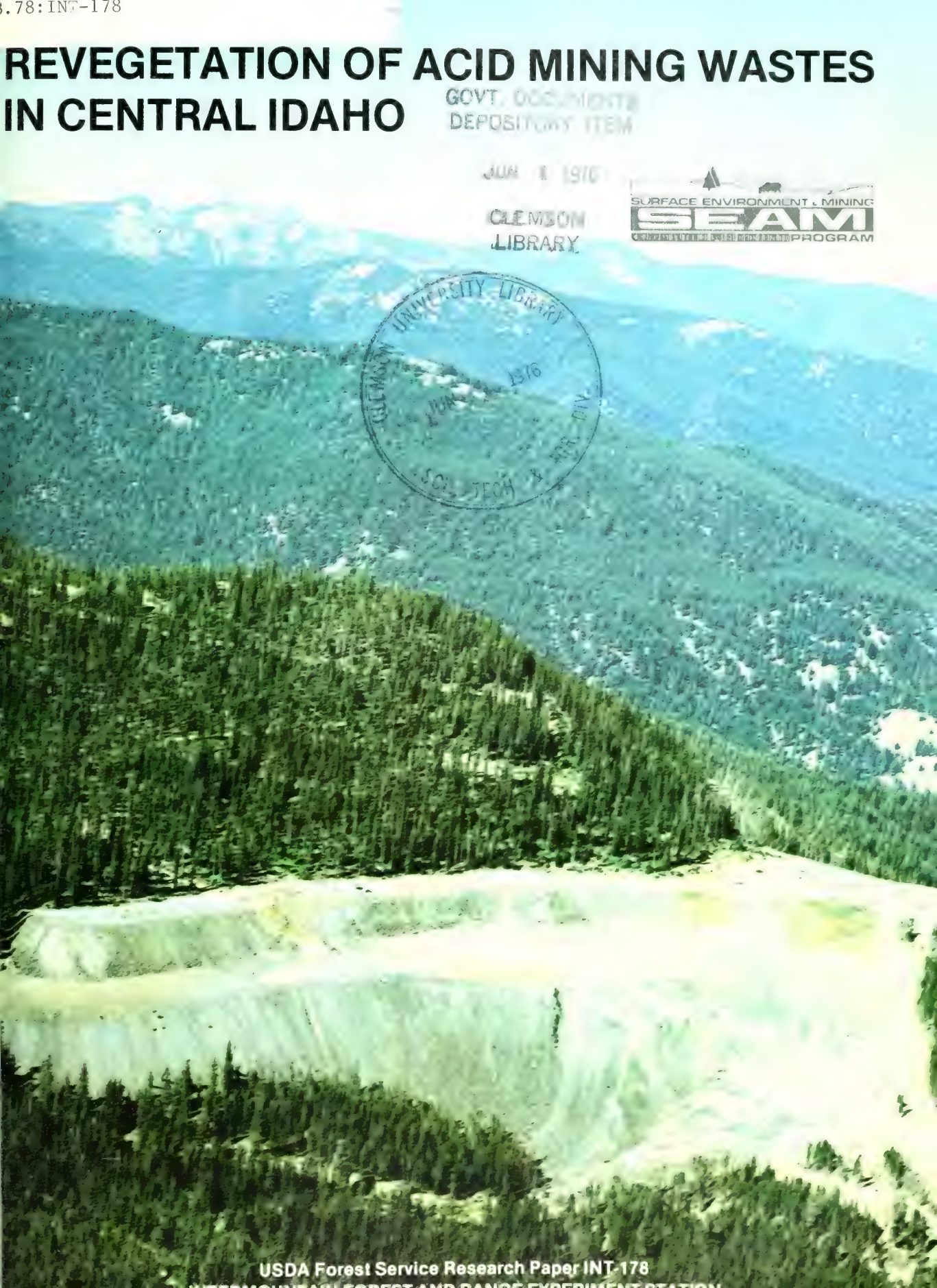

USDA Forest Service Research Paper INT-178
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION

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FRONT COVER PHOTO:

Revegetation research on the Blackbird, a copper-cobalt mine, is being conducted on this 1.1 million cubic yard waste pile. This mine is located on the Salmon National Forest about 25 air miles southwest of Salmon, Idaho. The top of the waste pile is at an elevation of 7,802 feet. Revegetation test plots are located on the south (left) end of the upper bench and on the sloping area at the north (right) end. This waste pile is approximately 20 years old and prior to treatment supported little vegetation because of severe soil acidity and low soil fertility. Treated areas appear as shades of green, white, and light brown. The predominant timber type is lodgepole pine.

INSIDE FRONT COVER PHOTO:

A color infrared oblique photograph of the waste pile shown on the cover. Due to the reflectance of chlorophyll in the infrared spectrum, healthy vegetation appears as shades of red or orange-red. Numbered spots are as follows:

1. Main test area, installed 1972.

2. Hydraulic seeding and hydromulch test plot.

3. Test of seeding methods and the addition of soil organic matter.

4. Freshly spread topsoil and native subsoils. The darker appearing materials have a greater soil moisture content.

5. The only notable invasion of vegetation for 20 years, six lodgepole pine saplings.

6. Low-grade ore dump area. See table 4, samples 1 to 5 for typical analyses.

7. Coarse rubble slope with spots of high concentrations of metallic salts. See table 4, sample 7, for analysis.

8. Phytotoxic concentrations of metallic salts killed the grass along the lower edge of this test area. See table 4, sample 6, for analysis.

USDA Forest Service
Research Paper INT-178
1976

REVEGETATION OF ACID MINING WASTES IN CENTRAL IDAHO

E. E. Farmer, B. Z. Richardson, and R. W. Brown

The research reported here was funded by the SEAM program. SEAM, an acronym for Surface Environment and Mining, is a Forest Service program to research, develop, and apply technology that will help maintain a quality environment and other surface values while helping meet the Nation's mineral requirements. SEAM is a partnership with all land managers, regional planners, mining industries, and political jurisdictions at all levels.

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

THE AUTHORS

EUGENE E. FARMER, Forest Hydrologist on the Watershed Protection and Rehabilitation research unit at Logan, Utah, joined the staff of Intermountain Station in 1964. His principal interests have been in soil erosion and precipitation characteristics in mountainous terrain. He has been engaged in surface mine rehabilitation activities since 1966.

BLAND Z. RICHARDSON is a Research Forester stationed at the Forestry Sciences Laboratory of Intermountain Station, Logan. After completing engineering training at Yale University in 1944, Richardson was commissioned in the U.S. Air Force where he served until his retirement from active duty in 1952. Richardson received his B.S. degree in forestry from the University of Montana in 1963. In 1964 he joined Intermountain Station and was assigned to work in the field of watershed management. Since then he has been involved in a variety of research activities in that field.

RAY W. BROWN is a Plant Physiologist with the Intermountain Station, stationed in Logan, since 1965. He received his B.S. and M.S. degrees in 1963 and 1965, respectively, from the University of Montana, and a Ph.D. in Plant Physiology in 1974 from Utah State University. His primary research interest and activity are in water relations and heat transfer characteristics of plants.

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ABSTRACT

The results of 2 years of revegetation research on acid mining wastes in central Idaho are described. Three types of main plots were used, each containing 12 treatments. Treatments are evaluated in terms of both vegetative production and ground cover. Vegetative species are evaluated in terms of their density and persistence under different treatment conditions. Coupled with a fertilization program, topdressing of mining wastes with selected overburden materials appears to be a highly desirable revegetation practice.

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INTRODUCTION

Acid soils and mine-acid waste and drainage waters are a problem on many mine operations in the Western United States. Erroneously, many people associate mine acid with western coal mining operations. This is understandable because most environmentally aware people have at least heard of the acid problems associated with coal mining in the eastern part of the United States. Usually, western coal mines are situated in alkaline soils. However, western mine-acid problems have the same origin as acid soil and water problems in the East, the oxidation of sulphide minerals. Western mine-acid problems are most often associated with ore production of uranium, lead, copper, cobalt, iron, chromium, platinum, and other metals at relatively high elevations with relatively high average annual precipitation.

One such mine is the Blackbird, a copper-cobalt mine on the Salmon National Forest near Salmon, Idaho. At this mine, elevations range between 6,600 and 8,200 feet. Average annual precipitation ranges from about 25 to 40 inches, with most precipitation falling as snow. The natural vegetation in the area is predominantly lodgepole pine *(Pinus contorta)* with an understory of huckleberry *(Vaccinium* spp.), Oregon grape *(Berberis repens)*, spirea, *(Spiraea* spp.*)*, pinegrass *(Calamagrostis rubescens)*, and some forbs. On disturbed sites such as road cuts the major vegetation is composed of bitterbrush *(Purshia tridentata)*, alder (*Alnus* spp.), rose *(Rosa woodsii)*, bluebunch wheatgrass *(Agropyron spicatum)*, Idaho fescue *(Festuca idahoensis)*, hairgrass *(Deschampsia caespitosa)*, western yarrow *(Achillea millefolium)*, and penstemon forbs and subshrubs *(Penstemon fruticosus)*.

The general physiography of the area is a rugged succession of high ridges with steep hillsides and deep, narrow draws. Although most draws are drained by perennial streams, the smallest draws support streamflow only during periods of active snowmelt, usually May and June. Naturally occurring acidity and concentrations of heavy metals are quite low in streams unaffected by mining. Normal pH of unaffected streams ranges between 6.2 and 6.6 with only trace amounts of metals. However, leachate from mining waste piles or from water flowing from deep mine openings may be of extremely low quality. The pH of these waters may run as low as 2.8 with copper concentration exceeding 100 p/m and iron concentrations of several hundred p/m.

The Blackbird Mining District has a long history. Gold was discovered in 1893 and copper at about the same time. From the late 1890's to the early 1940's ownership of the property changed from time to time and mining was opened and closed several times. No one seemed able to operate a profitable mining venture in the area. During World War II, the Federal Government conducted some exploration for a possible domestic source of cobalt in the area. After the war, private firms continued the exploratory effort and, in 1949, full-scale underground mining for copper and cobalt was started. With the onset of the Korean War, ore production and milling operations were expanded. The Blackbird Mine was active until 1960, but reached its peak production in 1958. It was reopened in 1963 with both a surface pit and an underground operation. All production operations were stopped in late 1967 and, except for exploratory work, the mine has been inactive ever since.

In general, the rocks of the Blackbird District are quartzites and metamorphosed Precambrian sediments. Occasional massive intrusions of chalcopyrite, cobaltite, pyrite, and pyrrhotite occur in mineralized lenses, the first two minerals are high-grade ores, the last two are waste sulphide minerals.

For more than 20 years the Mining District has been a massive contributor of sulphuric acid, copper and iron ions, mine tailings, and erosional products. These mining byproducts have killed all fishes and benthic organisms in Blackbird Creek, the major stream leaving the area. Blackbird Creek is tributary to Panther Creek, which, in turn, is tributary to the Salmon River. Copper ions and sulphuric acid have also eliminated the anadromous fishery in Panther Creek.

This report includes the results of 2 years of revegetation research on an overburden waste dump having a volume of approximately 1,100,000 cubic yards. Research was initiated the summer of 1972 and plantings were made in October of that year. At that time, the waste dump was virtually without vegetation, although it was almost 20 years old. The major long-term objective of this study is to provide several alternative prescriptions for achieving a permanent plant cover on the mining wastes of the Blackbird Mine. We believe the establishment of a permanent plant cover on the dump is prerequisite to reversing the trend away from the production of acid, heavy metal ions, and sediment.

METHODS

The study site is on level overburden material, chosen to avoid complications associated with seed and plant nutrient movement through erosional processes (fig. 1).

Three types of main plots were used: (1) a control plot on overburden material; (2) an irrigated plot on overburden material; and (3) a plot on which the overburden material was topdressed with about 8 inches of soil. These soil materials originated on nearby forest lands at depths ranging to 10 feet. Each main plot consists of 48 subplots, each 8 feet square, that constitute 12 treatments replicated four times. The 12 treatments included three seed mixtures, fertilizer and no fertilizer, and mulch and no mulch (table 1). The fertilizer application consisted of granular 18-46-0 fertilizer at the rate of 435 pounds per acre. Fertilizer was applied on appropriate subplots at planting time and also approximately 1 year later. The mulch application consisted of sphagnum peat moss spread at the rate of 2-1/2 tons per acre and covered with a single layer of jute netting. The three seed mixtures were (1) native species, (2) introduced species, and (3) a mixture of native and introduced species. All seed mixtures were applied at the rate of 25.5 pounds per acre (table 2).

Figure 1.--A general view, looking south, of the upper bench research site immediately after planting, October 1972. Steel rods mark subplot centers.

Table 1.--*Subplot treatments on each of three main plots*

Grass mixture	Fertilizer	Mulch
Native	Yes	Yes
Pasture	Yes	Yes
Native + Pasture	Yes	Yes
Native	Yes	No
Pasture	Yes	No
Native + Pasture	Yes	No
Native	No	Yes
Pasture	No	Yes
Native + Pasture	No	Yes
Native	No	No
Pasture	No	No
Native + Pasture	No	No

Table 2.--*Seed mixtures and seeding rates used in fall planting 1972*

Species		Seeding rate (lb/acre)
	NATIVE SPECIES	
Hairgrass	*Deschampsia caespitosa*	0.75
Bluebunch wheatgrass	*Agropyron spicatum*	3.0
Squirreltail	*Sitanion hystrix*	3.0
Basin wildrye	*Elymus cinereus*	8.25
Cheatgrass	*Bromus tectorum*	1.5
Western wheatgrass	*Agropyron smithii*	3.0
Balsamroot	*Balsamorhiza sagittata*	3.0
Western yarrow	*Achillea millefolium*	0.75
Goldenrod	*Solidago* sp.	2.25
		25.5
	INTRODUCED SPECIES	
Crested wheatgrass	*Agropyron cristatum*	3.0
Intermediate wheatgrass	*Agropyron intermedium*	4.5
Orchardgrass	*Dactylis glomerata*	3.0
Kentucky bluegrass	*Poa pratensis*	1.5
Timothy	*Phleum pratense*	4.5
Smooth brome	*Bromus inermis*	4.5
Meadow foxtail	*Alopecurus pratensis*	1.5
Alta fescue	*Festuca arundinacea*	1.5
Yellow sweetclover	*Melitotus officinalis*	1.5
		25.5
	NATIVE + INTRODUCED SPECIES	
Hairgrass	*Deschampsia caespitosa*	1.5
Timothy	*Phleum pratense*	3.0
Basin wildrye	*Elymus cinereus*	3.0
Orchardgrass	*Dactylis glomerata*	3.0
Intermediate wheatgrass	*Agropyron intermedium*	4.5
Western wheatgrass	*Agropyron smithii*	4.5
Smooth brome	*Bromus inermis*	3.0
Bluebunch wheatgrass	*Agropyron spicatum*	1.5
Crested wheatgrass	*Agropyron cristatum*	1.5
		25.5

Seed of native species was collected by hand and cleaned before being used. Most of the native species used in this work were collected in the vicinity of Cobalt, Idaho. Introduced species were purchased from commercial sources. All species selected for use appeared to have potential for revegetation; all occurred on such disturbances as road cuts and fills in the area.

The soils and overburden materials at the Blackbird Mine are not homogeneous. Spoils and ore-dump areas are especially heterogenous. These materials range from innocuous to highly toxic; most spoils are in the middle of the range, exhibiting low to moderate phytotoxicity. Results of analyses of native topsoils and subsoils used as topdressing and of spoil materials are shown in table 3. Plant-available nitrogen in these samples is negligible. Other areas on the waste dump are severely phytotoxic (table 4). These "hotspots" occupy only a small fraction in the study site and probably represent places where the overburden contained low-grade ores. They range in size from a few to about 10,000 square feet. These areas are particularly difficult to revegetate.

To support vegetative growth, all the overburden materials need lime. Even topdressing soil materials exhibit a lime requirement because of low base saturation. Burnt lime (CaO) was used as the liming agent. Two months before planting, the overburden materials were ripped to a depth of 10 inches and limed at the rate of 800 pounds CaO per acre; the topdressing soil was limed at the rate of 1,600 pounds CaO per acre. The topdressing soil required a greater liming rate than overburden materials because of greater cation exchange capacity. After the lime was spread over the surface, the site was harrowed several times to a depth of about 6 inches. No additional lime was applied during the period covered by this report.

At planting time, the soil materials were harrowed several times. Larger rocks, brought to the surface by harrowing, were removed with a rock rake. During planting, special measures were taken to insure that treatments were applied uniformly and that each was confined to the appropriate subplot area. The fertilizer and seed were separately packaged with silica sand, a carrying agent, and applied by a small seed

Table 3.--*Results of soil and spoil analyses. Samples 1 and 2 are topdressing soil; numbers 3 through 7 are spoil materials*

Sample	pH	Conductivity (µmhos/cm)	Cation exchange capacity (meq/100g)	Percent base saturation	p/m P	p/m K	p/m Cu	Texture
1	6.3	100	6.0	65	2	273	<1	silt loam
2	6.2	100	5.2	58	2	302	<1	silt loam
3	3.6	100	2.2	18	35	420	35	gravelly sand
4	3.5	300	2.1	24	29	428	3	gravelly sand
5	5.1	300	2.6	54	13	88	3	gravelly silt loam
6	4.8	400	2.2	48	14	107	7	gravelly silt loam
7	3.8	800	5.8	26	7	96	22	gravelly silt loam

Table 4.--*Results of overburden analyses on "hotspots," probably low-grade ore dumps. (Except for the pH and conductivity all units are parts per million)*

Sample Number	1	2	3	4	5	6	7
pH Units	3.90	4.10	3.75	3.90	4.00	4.50	4.20
Conductivity µmhos/cm	12,840	5,150	20,040	10,560	3,250	7,260	5,740
Aluminum	26,240	2,250	18,690	24,500	29,980	29,060	39,900
Arsenic	350	160	90	660	650	1,300	60
Barium	90	130	640	130	220	130	60
Boron	10	20	20	40	150	10	40
Cadmium	--	10	--	--	20	--	--
Calcium	1,200	1,130	2,800	2,910	2,250	1,670	500
Chloride	700	50	12,990	21,980	200	1,390	300
Chromium	20	30	50	20	30	30	20
Cyanide	50	--	450	10	10	10	20
Cobalt	280	100	70	500	520	1,110	50
Copper	23,160	26,500	37,400	16,590	7,890	25,510	28,960
Iron	100,570	88,530	68,110	71,590	69,000	94,270	124,410
Lead	30	20	20	30	40	30	20
Magnesium	7,630	6,380	14,550	7,950	1,920	7,190	4,900
Manganese	320	350	250	250	140	210	160
Mercury	--	--	--	10	20	50	20
Nitrate	40	20	20	30	10	10	10
Phosphate	30	1,500	1,330	1,550	1,700	950	900
Potassium	35,820	26,540	19,400	20,450	26,150	27,750	31,400
Selenium	10	10	20	--	30	--	--
Silica	290	300	1,830	150	130	80	60
Silver	--	10	10	--	20	--	30
Sulfate	30,500	29,400	64,970	41,900	1,650	31,500	21,750
Sodium	1,800	1,630	1,730	1,880	2,910	1,900	2,310
Zinc	40	50	60	30	50	80	40

spreader. Rice hulls were used with the seed. Fertilizer was applied and raked in. Then seed was applied and lightly raked. Mulch was applied where appropriate and a Brillion Culti-Packer used to pack the whole area.

From June through September 1973 (the first growing season), water was applied on the irrigated main plot in three weekly applications of one-quarter inch each. From June through September 1974 (the second growing season) water was applied at no set irrigation schedule. Irrigation water was applied "as needed" on the basis of visual observations of plant turgor and length of time since last irrigation or rainfall. Irrigation water was obtained from a nearby creek and hauled to the research site. It was applied through a sprinkler irrigation system with a high degree of uniformity.

Two types of data were collected from each of the 144 subplots: stand density and estimates of the dry-weight herbage production. During data collection, all measurements and counts were made on the interior 6- by 6-foot area of each subplot. In effect, this action separated subplot treatments by a buffer zone 2 feet wide.

Early in the first growing season, grass seedling emergency was assessed by making density estimates on the topdressed plot and on the control plot only. All seedlings were counted on a randomly selected 10-square-foot area of each subplot.

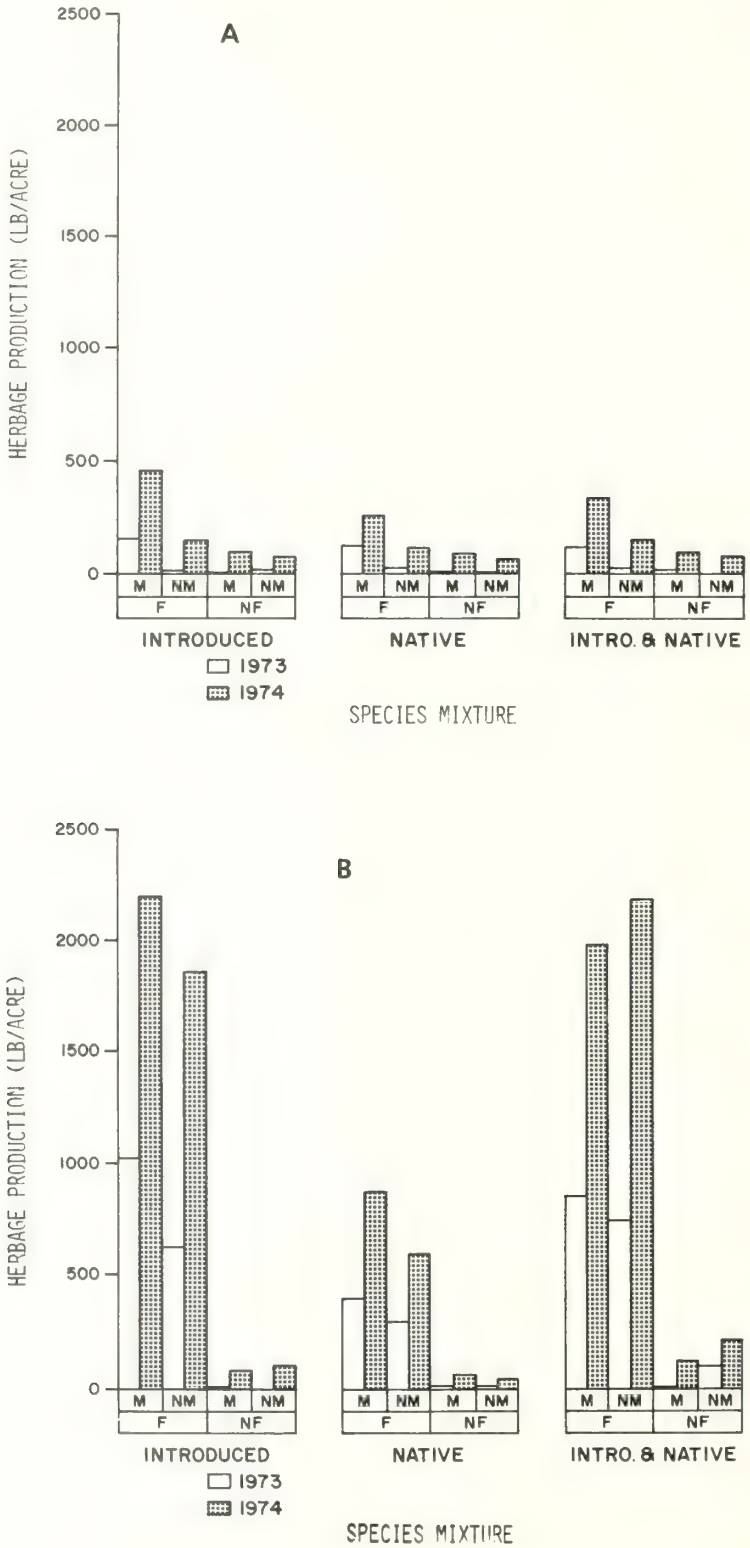
To determine the dry-weight production of vegetation on each subplot, plots were assessed during October 1973 and September 1974. In the assessment work, nondestructive sampling was imperative since future measurements would be required. Therefore, the Neal capacitance meter, model 18-1000, was used to estimate production (Neal and Neal 1973). To calibrate the capacitance meter, one of every six herbage plots read with the meter was clipped, dried, and weighed. Each herbage plot measured 1 by 2 feet.

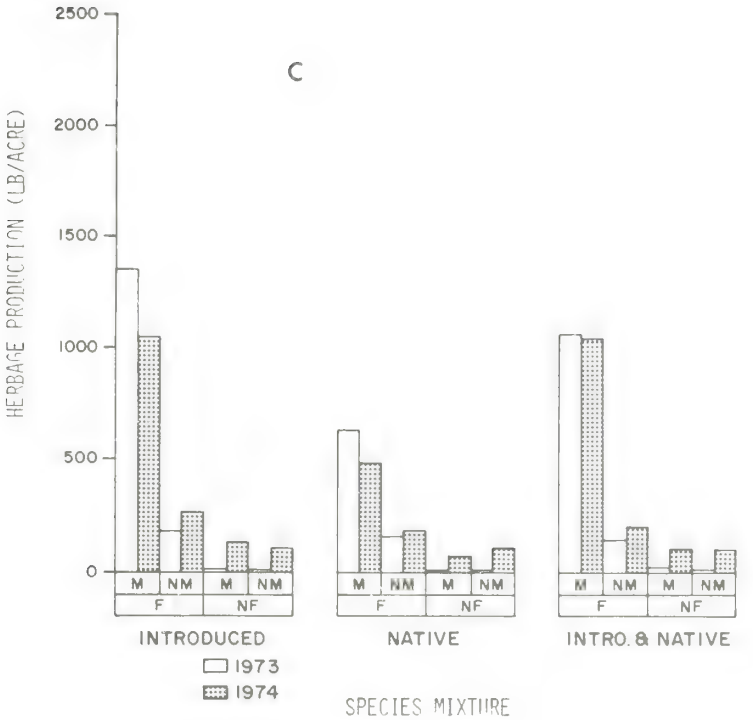
RESULTS

During the two growing seasons reported here, weather conditions were neither unusually severe nor especially favorable. Over the first growing season when the plants were becoming established, the May through August precipitation was about 22 percent below the 10-year mean. However, September precipitation was about 60 percent over the mean. During the second growing season, precipitation for June and July was about 60 percent below the mean, but precipitation for May and August was about 28 percent greater than the mean. Average air temperatures during the first two growing seasons exhibited deviations both above and below the 10-year mean; however, the research area was slightly warmer than normal.

Figure 2 shows the dry-weight vegetative production for the two growing seasons. Generally, the smallest yields have come from the native species and the largest yield from the mixture of introduced grasses. This was the expected result. The native species have performed reasonably well, especially on the topdressed plot. Growth comparisons between 1973 and 1974 generally show a favorable increase during the second growing season. The only exception were the yields of some treatments on the irrigated main plot.

Figure 8.--Average dry-weight vegetative production, Blackbird Mine, compared for 1973 and 1974: A, control main plot, B, topsoil main plot, and C, irrigated main plot.





Data on both seedling emergence and dry-weight production were tested for differences by analyses of variance. The 95 percent probability level was used to determine significant differences. Throughout this paper, 1974 data were used for analyses of variance on dry-weight production. The 1973 data are reported only to point out significant changes between 1973 and 1974. Data on seedling emergence were collected in early spring 1973.

Control Plot

Seedling emergence on the control plot was entirely satisfactory regardless of subplot treatment. Seedling counts ranged from 12 to 38 per square foot; the average was 25 per square foot. The following points describe the effects of seed mixture, mulch, and fertilizer on seedling emergence.

1. Seedling emergence differed significantly due to seed mixtures. The introduced species emerged best ($34/ft^2$), the native + introduced species next ($26/ft^2$), and the native mixture poorest ($14/ft^2$).

2. Mulch caused no significant difference in seedling emergence.

3. The effect of fertilizer on seedling emergence varies with the mulch treatment. Fertilizer had no effect on unmulched plots, but on mulched plots, it significantly increased seedling emergence (21 versus $29/ft^2$).

As expected, the control plot produced less plant material than either of the other main plots (fig. 2A). The stands on the control plot have made large percentage increases in weight during the second growing season, but even the best stands are only marginally acceptable in terms of providing protection against accelerated soil erosion. Without exception, both mulch and fertilizer produced the best stands.

The following points describe the effects of seed mixture, mulch, and fertilizer on dry-weight grass production.

1. Seed mixtures caused no difference in dry-weight production.

2. Mulch significantly increased the production of all mixtures.

3. Mulch and fertilizer interacted significantly--the effect of fertilizer depended on the mulch treatment. On unmulched plots, the positive effect of fertilizer was small (76 vs. 132 lb/acre vegetation). On mulched plots fertilizer has a large positive effect (94 vs. 356 lb/acre vegetation).

Topdressed Plot

Seedling counts on the topdressed plot ranged from 13 to 46 per square foot; the average was 29 per square foot. These counts are high enough to potentially produce good stands of vegetation. The following points describe the effects of seed mixture, mulch, and fertilizer on seedling emergence.

1. Seedling emergence showed a significant difference due to seed mixtures. The introduced species emerged best ($40/ft^2$), the native + introduced species next ($31/ft^2$), and the native mixture poorest ($15/ft^2$).

2. There was a significant difference due to mulch, but the effect varied with species mixture. Mulch decreased the emergence of both the introduced species mixture, and the native + introduced mixture. Mulch had no effect on the emergence of native species.

3. Fertilizer had no effect.

Among main plots, the topdressed plot produced the greatest average yields. At the end of the first growing season (1973), the greatest yields were on the irrigated main plot. However, during the second growing season, the topdressed main plot surpassed the irrigated main plot in vegetative production. Fertilized subplots have given particularly good yields (fig. 2B). The following points result from an analysis of the dry-weight production data:

1. The two seed mixtures that contained introduced grass species produced significantly greater yields than did the native species. However, yields produced by the introduced mixture and the native + introduced mixture were not different from each other.

2. Mulch had no effect on production.

3. Fertilizer increased the production of all species mixtures. Fertilizer benefits were in the following order: introduced species > native + introduced species > native species.

Irrigated Plot

Seedling emergence counts were not made on the irrigated plot. However, limited count data and visual estimates convinced the authors that seedling counts on the irrigated plot would produce results similar to the counts made on the control plot.

During the first growing season, the dry-weight vegetative production on the irrigated plot was greater than on either of the other two main plots. In the second growing season, the irrigated plot did not make much additional growth and the greatest yielding subplots showed a decline in dry-weight production of as much as 23 percent (fig. 2C). The reasons for the decline in production from fertilized and mulched subplots are not completely known. However, results of soils analyses indicate that these subplots are reacidifying more rapidly than other irrigated sub-

plots. Reacidification, aside from the obvious effect on pH, is accompanied by increases in the solubility of metal ions in the soil solution and changes in plant nutrient availability (Nielson and Peterson 1972). These changes, and probably others, are thought to be involved with the production decline during the second growing season. Work now in progress should help to clarify the adverse influences of reacidification.

The following points result from an analysis of dry-weight production data:

1. The difference in production due to seed mixture was significant; the native plants produced significantly less weight than the other two mixtures.

2. Mulch and fertilizer interact in such a way that mulch had a significant effect only on fertilized plots. On unfertilized plots, mulch had no effect.

3. Fertilizer increased the production of all three grass mixtures. Fertilizer benefits were in the following order: introduced species > native + introduced species > native species.

Plant Cover

Due to the relation between soil erosion and acid production on waste piles, soil erosion on mining disturbances associated with sulphide minerals merits special consideration. Since acid soils and acid drainage water both result from the oxidation of sulphide minerals located on or near the soil surface, the stability of surface materials is a major influence on acid production. If erosion is continually exposing new, unoxidized materials, the processes of sulphide oxidation and soil erosion form a positive feedback cycle that tends to perpetuate high rates of acid production (Ohio State University 1971).

The effectiveness of vegetation in reducing soil erosion is well known. The canopy protects the surface materials from raindrop impact and consequent detachment of soil particles. Vegetation also reduces the velocity of surface runoff, which reduces the cutting action of water and its ability to carry soil particles. Vegetative root systems effectively improve soil structure and porosity. The entire vegetative system moderates the microclimate and provides cover and nutrient sources for beneficial microfauna and flora. Finally, plant transpiration dries the surface and retards the upward movement and surface deposition of soil salts.

Due to differences in plant morphology, soil-erosion control is rarely related to the dry-weight production of vegetation. Ground cover density is a better parameter than production for estimating erosion control (Packer 1951; Meeuwig 1971). Photographic techniques were used to obtain ground cover density estimates for each of the 144 subplots on the Blackbird Mine. These density estimates were then regressed against the clipped and measured weight of vegetation. The simple regression equation is:

$$\hat{Y} = 8.88 + 1.62(X)$$

where:

$\hat{Y}$ = aerial ground cover density, percent

X = vegetation, dry weight (grams) per 2 square feet; $X \leq 56.25$

The standard error of estimate and coefficient of determination (r^2) are 7.8 and 92 percent, respectively. Average ground cover density for each series of four treatment replications is shown in table 5.

Table 5.--*Average ground cover density, percent, for three series of four treatments, by main plots*

Treatment code	Ground cover density, percent		
	Control plot	Topdressed plot	Irrigated plot
N-F-M	18	39	25
N-F-NM	13	29	15
N-NF-M	12	11	11
N-NF-NM	11	8	13
P-F-M	25	83	44
P-F-NM	14	72	18
P-NF-M	12	11	13
P-NF-NM	11	12	12
NP-F-M	20	76	44
NP-F-NM	14	78	16
NP-NF-M	12	13	13
NP-NF-NM	11	12	12

N = native species mixture
P = introduced pasture grass mixture
NP = native + introduced species mixture
F = fertilized
NF = not fertilized
M = mulch
NM = not mulched

Evaluation of Treatments

To facilitate evaluation of treatments, vegetation yield means were grouped by seed mixture and ranked by treatment, table 6. This grouping combines the results from control, irrigated, and topdressed plots and is useful for making comparisons among the treatments for each seed mixture. Regardless of seed mixture, the two greatest yields occurred on fertilized topdressed plots. For all seed mixtures, the fertilized and mulched irrigated plots ranked third. Third and fourth ranked treatments were widely separated. In fact, for each species mixture, the fourth ranking treatment was so poor that it is probably safe to ignore treatment numbers 4 through 12 as potential revegetation alternatives. This idea is supported by the data in table 5, which shows that 25 percent is the greatest average ground cover density of any fourth ranking treatment. This is not sufficient ground cover to protect the soil surface from accelerated water erosion. However, these vegetative stands are only 2 years old and the progress of all treatments will be followed for several more years.

At this time, topdressing with native top soils and subsoils appears to offer the best chance for the successful revegetation of waste piles of the Blackbird Mine. Fertilizer also appears to be a requirement for successful revegetation. On unfertilized subplots, ground cover averaged 12 percent at most. Whether or not a mulching treatment is required, especially on topdressed plots, is not known; however, mulch does not appear to be required.

Table 6.--*Average dry-weight vegetative production by treatment, ranked within seed mixtures*

Rank	Native species		Introduced species		Native + introduced species	
	Treatment	Dry weight: lb/acre	Treatment	Dry weight: lb/acre	Treatment	Dry weight: lb/acre
1	T-F-M	886	T-F-M	2,206	T-F-NM	2,100
2	T-F-NM	598	T-F-NM	1,859	T-F-M	1,978
3	I-F-M	490	I-F-M	1,037	I-F-M	1,039
4	C-F-M	271	C-F-M	463	C-F-M	328
5	I-F-NM	186	I-F-NM	281	T-NF-NM	211
6	I-NF-NM	111	C-F-NM	140	I-F-NM	210
7	C-F-NM	109	I-NF-M	118	C-F-NM	146
8	C-NF-M	89	T-NF-NM	107	T-NF-M	114
9	I-NF-M	72	I-NF-NM	103	I-NF-M	111
10	C-NF-NM	71	C-NF-M	96	I-NF-NM	107
11	T-NF-M	65	C-NF-NM	79	C-NF-M	87
12	T-NF-NM	47	T-NF-M	77	C-NF-NM	79

T = topdressed main plot
C = control main plot
I = irrigated main plot

F = fertilized
NF = not fertilized
M = mulched
NM = not mulched

Species Evaluation

Clearly, those seed mixtures that contain introduced grasses are producing more vegetation than the native mixture (fig. 2 and table 6). However, several items must be considered beyond dry-weight production, including the long-term ability to survive adverse conditions of soils, climate, insects, and diseases. Definitive species evaluation will take longer than 2 years. However, several interesting and informative trends are apparent.

On all subplots in both 1973 and 1974, estimates of plant density, by species, were obtained from subsamples of each subplot. These data are tabulated in table 7. On the better vegetated subplots, plant densities generally decreased from 1973 to 1974; however, vegetative production usually increased as individual plants grew larger and more vigorous. Also, species diversity generally decreased, as less well-adapted species die out. Some subplots that were essentially bare in 1973 exhibited low plant densities in 1974. However, vegetation production was also low.

Among the native species mixture, squirreltail *(Sitanion hystrix)*, western yarrow, and cheatgrass *(Bromus tectorum)* appear to be dominant. Interestingly, hairgrass does not appear on the native mixture plots, but it does appear on the plots of mixed introduced and native species. Hairgrass apparently does not compete well against other pioneer plants indigenous to the Blackbird Mine area. Western yarrow has a high propensity to survive adverse soil chemistry and nutrient conditions, with or without supplemental irrigation.

Among the introduced species, orchardgrass *(Dactylis glomarata)*, timothy *(Phleum pratense)*, and smooth brome *(Bromus inermis)* appear to be dominant, with small admixtures of meadow foxtail *(Alopecurus pratensis)*. Orchardgrass apparently can survive adverse soil chemistry better than the other species. Wheatgrasses are not surviving well and probably will be lost in spite of a good start in 1973.

Table 7.--Species composition and standing density per square foot by species (1973 and 1974), and treatment on spoil mixtures[1]

Treatment code[1]	1973 Control Species	1973 Control Density	1973 Topsoil Species	1973 Topsoil Density	1973 Water Species	1973 Water Density	1974 Control Species	1974 Control Density	1974 Topsoil Species	1974 Topsoil Density	1974 Water Species	1974 Water Density
N-F-M	Wheatgrass	5.38	Wheatgrass	6.00	Wheatgrass	3.25	Squirreltail	2.25	Squirreltail	5.50	Yarrow	2.13
	Squirreltail	3.88	Yarrow	2.25	Squirreltail	2.25	Yarrow	1.50	Yarrow	4.38	Squirreltail	1.38
	Cheatgrass	.75	Squirreltail	2.00	Yarrow	2.25			Wheatgrass	1.13		
	Yarrow	.50	Cheatgrass	2.00	Cheatgrass	1.50						
N-F-NM	None*		Wheatgrass	5.00	Wheatgrass	2.75	Squirreltail	1.88	Squirreltail	4.25	Squirreltail	1.75
			Squirreltail	2.75	Squirreltail	1.88	Yarrow	.25	Yarrow	2.50	Yarrow	.75
			Wheatgrass	1.75	Cheatgrass	.63			Wheatgrass	2.38		
			Yarrow	.63	Yarrow	.63						
N-NF-M	None*		None*		Yarrow	0.63	Yarrow	0.88	Yarrow	1.63	Yarrow	1.88
							Cheatgrass	.50	Cheatgrass	.25		
N-NF-NM	None*		None*		Yarrow	1.25	Yarrow	1.50	Yarrow	1.25	Yarrow	1.38
							Cheatgrass	.25	Cheatgrass	.25		
P-F-M	Wheatgrass	4.88	Timothy	13.25	Timothy	8.25	Timothy	3.38	Timothy	11.63	Smoothbrome	5.38
	Orchardgrass	3.50	Wheatgrass	5.75	Wheatgrass	3.50	Smooth brome	3.00	Smooth brome	3.13	Timothy	3.63
	Timothy	3.13	Orchardgrass	3.88	Orchardgrass	2.69	Orchardgrass	.63	Meadow foxtail	1.75	Meadow foxtail	1.50
	Alta fescue	1.25	Smooth brome	1.25	Smooth brome	.63	Meadow foxtail	.25			Alta fescue	.38
	Smooth brome	.25	Alta fescue	.50	Alta fescue	.63						
					Meadow foxtail	.38						
P-F-NM	Timothy	0.50	Timothy	8.00	Timothy	2.13	Smooth brome	0.38	Orchardgrass	14.25	Orchardgrass	0.75
	Alta fescue	.50	Orchardgrass	7.63	Wheatgrass	1.63	Meadow foxtail	.38	Timothy	7.88	Meadow foxtail	.75
	Wheatgrass	.25	Wheatgrass	5.75	Orchardgrass	.88			Smooth brome	1.88	Timothy	.50
			Smooth brome	1.63	Alta fescue	.50			Meadow foxtail	.75	Smooth brome	.38
			Alta fescue	.75	Smooth brome	.38						
			Meadow foxtail	.25								
P-NF-M	None*		Orchardgrass	3.00	None*		None*		Orchardgrass	3.38	None*	
P-NF-NM	None*		None*		None*		Orchardgrass	0.50	Orchardgrass	1.75	None*	
NP-F-M	Orchardgrass	6.63	Timothy	9.38	Wheatgrass	4.50	Smooth brome	1.00	Timothy	13.00	Smooth brome	4.00
	Wheatgrass	5.75	Wheatgrass	6.38	Orchardgrass	3.75	Orchardgrass	.38	Orchardgrass	12.13	Orchardgrass	1.75
	Timothy	3.00	Orchardgrass	5.38	Hairgrass	1.50	Timothy	.38	Smooth brome	3.00	Timothy	1.50
	Hairgrass	1.13	Smooth brome	1.00	Smooth brome	.75			Wheatgrass	1.75	Wheatgrass	.75
	Smooth brome	.50										
NP-F-NM	Wheatgrass	2.50	Orchardgrass	10.50	Wheatgrass	4.88	None*		Orchardgrass	11.00	Smooth brome	0.50
	Orchardgrass	.63	Wheatgrass	7.00	Orchardgrass	3.00			Timothy	9.63	Hairgrass	.50
	Smooth brome	.25	Timothy	6.88	Timothy	1.38			Wheatgrass	2.38	Yarrow	.50
			Smooth brome	1.13	Smooth brome	.63			Smooth brome	1.88	Timothy	.38
			Hairgrass	.63								
NP-NF-M	None*		None*		None*		Orchardgrass	0.75	Orchardgrass	4.50	Hairgrass	0.38
									Hairgrass	1.13		
NP-NF-NM	None*		None*		Hairgrass	0.38	Hairgrass	1.38	Orchardgrass	1.75	Hairgrass	1.63
									Hairgrass	.25	Squirreltail	.88

[1]See table 5 for code identification.
*Densities less than 0.25/ft² are not shown.

With data covering only two growing seasons, it appears that orchardgrass, timothy, and smooth brome will produce good grass stands, especially on areas topdressed and fertilized. However, it would probably be a serious mistake to ignore native pioneer species, in spite of their lower dry-weight production. Squirreltail, yarrow, cheatgrass, and perhaps hairgrass appear to be capable of survival under the most adverse conditions. A seed mixture comprised of these introduced and native species would be expected to show good production and ground cover under good growing conditions and yet would be capable of producing an adequate stand of vegetation under adverse conditions.

DISCUSSION

This study was designed to test a broad spectrum of potential treatments to determine the minimum combination of different treatments necessary to provide an acceptable plant cover. These results, covering only 2 years, do not conclusively indicate that minimum combination. However, strong trends in the data suggest treatments that may be most acceptable. Topdressing of mining wastes with native topsoils or subsoils to a depth of 8 inches or more, coupled with a fertilization program, appears to be highly desirable. Irrigation of untreated waste piles for the establishment of vegetation is of questionable value, but cannot be completely dismissed as yet. An unanswered question regarding supplemental irrigation involves the effects of stopping irrigation. These plots will not be irrigated in succeeding growing seasons and the effects of irrigation cessation will be studied. Revegetation of raw mining wastes, even with inputs of lime, fertilizer, and mulch, does not appear to be a desirable alternative.

There are no indications that topdressing materials or mining wastes, treated with a liming agent, had significant adverse effects on either seed germination or seedling emergence. However, thorough seedbed preparation and seed packing are essential to ensure hydraulic contact with the soil. These factors should be considered in pilot or large-scale revegetation attempts. Special measures may be required to ensure hydraulic seed contact in rocky waste piles.

Species evaluation work will continue for several more years. The results on irrigated-fertilized-mulched plots will be especially interesting since the 1974 growing season was the last season of supplemental irrigation. The data so far seem to indicate that a mixture of orchardgrass, timothy, smooth brome, squirreltail, western yarrow, cheatgrass, and perhaps hairgrass will produce satisfactory stands across a wide range of soil chemical and nutrient conditions. In a somewhat oversimplified view, the introduced grasses will produce good stands under the best conditions, the native species will provide some cover under adverse conditions, and admixtures of native and introduced species will provide stands across a wide range of intermediate soil conditions. However, even native species have definite, if undefined, limitations. Low-grade ore pockets or dumps that are high in sulphide minerals and salts probably will not support vegetative growth. These phytotoxic materials will have to be buried.

Some important questions that this research is not designed to answer quickly involve the continued use of fertilizers. Whereas initial fertilization appears to be a strict requirement, we do not know how long the effects will last, or if fertilization of revegetated areas will be a continued requirement at periodic intervals. Undoubtedly these answers partly lie in the complex soil chemistry of acid sulphide soils because plant nutrient availability and plant respiration processes are differentially affected by soil pH. These answers are also inextricably tied to land management goals and long-term land use plans. If high quality surface water showing only trace amounts of acidity and heavy metals is required from this area, plant fertilization will probably be required at periodic intervals for a long time. Reduced land management goals will require smaller physical inputs to maintain the system.

Reacidification of the study site is expected to be a problem, although the difficulty or magnitude of the problem has not yet been defined. The study site was limed in 1972 and, by 1974, some subplots showed signs of moderate to strong reacidification, especially those on the irrigated main plot. The grass clumps shown on the lower inside back cover were growing about 24 inches apart, but the grass on the left side was growing on a spot that is strongly reacidifying, with a soil pH of 3.4 in the surface 8 inches. Without reliming this grass would rapidly die. The grass on the right side still shows good growth and root development in a soil with a pH of 5.0. Without reliming, it would also die over a 1- to 2-year period, depending upon the reacidification rate. Results of plant tissue analyses for the grass clumps shown on the inside back cover are reported in table 8. Notice that the content of potassium, iron, copper, and zinc in the plant tissues is much greater on soil with a pH of 3.4 than on soil with a pH of 5.0. The application of fine agricultural limestone is expected to correct the reacidification problem. However, to date, no adverse vegetative effects of reacidification have been detected on the main plot that was topdressed with 8 inches of native topsoils and subsoils.

Table 8.--*Results of plant tissue analyses for plants growing on raw mine spoils that have strongly reacidified (soil pH = 3.4) or moderately reacidified (soil pH = 5.0)*

Element	Soil pH = 3.4			Soil pH = 5.0		
	Shoots	Meristem	Roots	Shoots	Meristem	Roots
Nitrogen	18,000	12,000	NA	11,000	8,400	7,400
Sulfur	3,500	4,600	NA	2,700	2,400	3,200
Phosphorus	3,000	3,200	1,200	2,900	1,600	1,300
Potassium	23,500	10,000	6,800	18,000	6,000	1,700
Magnesium	800	900	1,000	700	900	200
Calcium	5,600	7,200	3,500	6,500	3,500	6,000
Sodium	200	125	115	275	350	137
Iron	265	11,800	11,770	525	2,800	3,200
Manganese	35	46	103	62	18	98
Boron	7	4	1	8	1	5
Copper	70	400	497	28	160	108
Zinc	180	160	44	15	23	60

PUBLICATIONS CITED

Neal, D. L., and J. L. Neal.
1973. Uses and capabilities of electronic capacitance instruments for estimating standing herbage. J. Br. Grassland Soc. 28:81-89.

Meeuwig, R. O.
1971. Soil stability on high-elevation rangeland in the Intermountain area. USDA For. Serv. Res. Pap. INT-94, 10 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Nielson, R. F., and H. B. Peterson.
1972. Treatment of mine tailings to promote vegetative stabilization. Utah State Univ. Agric. Exp. Stn Bull. 485. Logan, Utah.

Ohio State University Research Foundation.
1971. Acid mine drainage formation and abatement. Water Quality Office, Environ. Protection Agency W71-08591, Washington, D.C.

Packer, P. E.
1951. An approach to watershed protection criteria. J. For. 49:639-644.

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

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Farmer, E. E., B. Z. Richardson, and R. W. Brown
1976. Revegetation of acid mining wastes in central Idaho. USDA For. Serv. Res. Pap. INT-178, 17 p., 5 ref. Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.

The results of 2 years of revegetation research on acid mining wastes in central Idaho are described. Three types of main plots were used, each containing 12 treatments. Treatments are evaluated in terms of both vegetative production and ground cover. Vegetative species are evaluated in terms of their density and persistence under different treatment conditions. Coupled with a fertilization program, topdressing of mining wastes with selected overburden materials appears to be a highly desirable revegetation practice.

OXFORD: 268:41; 237.
KEYWORDS: surface mine revegetation, revegetation research, acid mining wastes, acid mine drainage, waste dump revegetation, regrassing.

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INSIDE BACK COVER, UPPER:

A vertical color infrared photograph of the three revegetation main plots, August 1974. Numbered spots are as follows:

1. The irrigated main plot, with 48 subplots. Irrigation was a definite aid in establishing plant cover. However, it also speeds the reacidification of limed wastes, which is detrimental to the vegetation. See inside back cover, lower, and table 8.

2. The control main plot, with 48 subplots. The degree of vegetative cover is directly related to the intensity of the red color.

3. Topsoiled main plot, with 48 subplots. Fertilized subplots appear red or orange-red, depending upon seed mixture. Brown (nonfertilized) and light-beige (mulched-nonfertilized) subplots contain little vegetation.

4. A salt seep emanating from the base of the upper bench. These whitish salts are severely phytotoxic.

5. An area with relatively high concentrations of metallic salts. The electrical conductivity of these soils is about 8,000 μmhos/cm., and contain high concentrations of heavy metals. For instance, see table 4, sample 7.

INSIDE BACK, LOWER:

Grass clumps growing on mine spoils show the effects of reacidification of spoil material. The grass on the left grew on a spot that was strongly reacidifying, with a soil pH of 3.4. The grass on the right grew 24 inches away in a soil with a pH of 5.0. If the study site is not relimed, both grasses will die. Yellow leaf parts are necrotic areas; the extent of necrosis depends upon the reacidification rate and degree.

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Vegetative assessment work on the copper-cobalt Blackbird Mine, September 1974. Each subplot occupies an 8- by 8-foot area, indicated by the patchwork appearance of different treatments. Some of the treatments have yielded good stands of grass. The left background shows an untreated portion of the waste dump that contains low-grade ores. See table 4, sample 4, for analysis.